Preliminary Assessment of Impact of Tsunami in Selected Coastal Areas of India

Compiled by

Department of Ocean Development
Integrated Coastal and Marine Area Management Project Directorate
Chennai

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1 Background

Tsunamis are among the most terrifying natural hazards known to man and have been responsible for tremendous loss of life and property throughout history. Because of their destructiveness, tsunamis have notable impact on the human, social and economic sectors of our societies. In the Pacific Ocean, where the majority of these waves have been generated, the historical record shows wide scale destruction. In Japan, which has one of the most populated coastal regions in the world and a long history of earthquake activity, tsunami has destroyed large coastal populations. There is also a history of tsunami destruction in Alaska, in the Hawaiian Islands in South America, Japan and elsewhere in the Pacific.

Destructive tsunamis have also occurred in the Indian Ocean and in the Mediterranean Sea. The most notable tsunami in the region of the Indian Ocean was that associated with the violent explosion of the volcanic island of Krakatoa in August 1883. A 30 m (100 feet) tsunami resulting from this explosion killed 36,500 people in Java and Sumatra. The violent eruption and explosion of the volcano of Santorin, in the fifteenth Century B.C. generated a giant tsunami which destroyed most of the coastal Minoan settlements on the Aegean Sea islands acting as the catalyst for the decline of the advanced Minoan civilization.

Tsunamis that can travel across an ocean and attack a coastal area far away from the source of generation are called distant Tsunamis or Teletsunamis, while tsunamis that are confined in an area near the source are called local Tsunamis.

2 History of Tsunamis affecting Indian Ocean

Although not as frequent as in the Pacific Ocean, tsunamis generated in the Indian Ocean pose a great threat to all the countries of the region. The most vulnerable are: Indonesia, Thailand, India, Sri Lanka, Pakistan, Iran, Malaysia, Myanmar, Maldives, Somalia, Bangladesh, Kenya, Madagascar, Mauritius, Oman, Reunion Island (France), Seychelles, South Africa and Australia.

Tsunamis occur seldom in the Indian Ocean region, and in the last 300 years, this region recorded 13 tsunamis (Table 1) and 3 of them occurred in Andaman and
Nicobar region for which the details of location of epicentre, death/damage caused etc. are not known, data on run-up heights indicate to the extent of 4 m in Port Blair with Nicobar recording very low (0.76 m). (Run-up level is defined as the max. elevation in land upto which it is inundated by seawater during tsunamis). Among these, the 1945 tsunami had a maximum run up of 13 m in Pakistan and resulted in death of 4000 people following an earthquake of magnitude 8.2 Ms in the Arabian Sea. Overall, the run-up levels varied from 1 to 13 m. In 1977, one of the strongest earthquake of magnitude Ms 8.1 struck west of Sumba Island in Indonesia, but there were no reports of casualties in India due to this tsunami. Apart from those listed in Table 1, there may be additional destructive tsunamis in the Indian Ocean that have not been properly documented. For example villagers of Simeulue Island, off the coast of Sumatra, speak of a destructive tsunami in 1907 that had killed thousands of people.

**TABLE 1. Run-up level for Tsunami occurred between 1700 and 2004 in the Indian Ocean**

<table>
<thead>
<tr>
<th>S. No</th>
<th>Name of affected location</th>
<th>Run up heights (m)</th>
<th>Year/Date</th>
<th>Earthquake Magnitude at source</th>
<th>Source location</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Tributaries of the Ganges river (Bangladesh)</td>
<td>1.83</td>
<td>12.04.1762</td>
<td>NA</td>
<td>Bay of Bengal</td>
</tr>
<tr>
<td>2.</td>
<td>--</td>
<td>--</td>
<td>1847</td>
<td>--</td>
<td>Great Nicobar Island</td>
</tr>
<tr>
<td>3.</td>
<td>Port Blair, Andaman Islands</td>
<td>4.00</td>
<td>19.08.1868</td>
<td>MW 7.5</td>
<td>Bay of Bengal</td>
</tr>
<tr>
<td>4.</td>
<td>Car Nicobar Island, Nicobar Islands</td>
<td>0.76</td>
<td></td>
<td></td>
<td>Car Nicobar Islands, Andaman Sea</td>
</tr>
<tr>
<td>5.</td>
<td>Dublat, India</td>
<td>0.30</td>
<td>31.12.1881</td>
<td>MS 7.9</td>
<td>Car Nicobar Islands, Andaman Sea</td>
</tr>
<tr>
<td>6.</td>
<td>Nagapattinam, India</td>
<td>1.22</td>
<td></td>
<td></td>
<td>Car Nicobar Islands, Andaman Sea</td>
</tr>
<tr>
<td>7.</td>
<td>Port Blair, Andaman Islands</td>
<td>1.22</td>
<td></td>
<td></td>
<td>Car Nicobar Islands, Andaman Sea</td>
</tr>
<tr>
<td>8.</td>
<td>Chennai</td>
<td>1.5 (wave height)</td>
<td>26.08.1883</td>
<td>Krakatoa volcanic eruption</td>
<td>Islands of Java and Sumatra</td>
</tr>
<tr>
<td>9.</td>
<td>Andaman &amp; Nicobar Islands</td>
<td>NA</td>
<td>26.6.1941</td>
<td>MW 7.7</td>
<td>Andaman Sea (12.5°N; 92.57°E)</td>
</tr>
<tr>
<td>S. No</td>
<td>Name of affected location</td>
<td>Run up heights (m)</td>
<td>Year/Date</td>
<td>Earthquake Magnitude at source</td>
<td>Source location</td>
</tr>
<tr>
<td>------</td>
<td>--------------------------------------------------------</td>
<td>--------------------</td>
<td>-----------------</td>
<td>-------------------------------</td>
<td>---------------------------------</td>
</tr>
<tr>
<td>10.</td>
<td>Mumbai, India</td>
<td>1.98</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11.</td>
<td>Karachi, Pakistan</td>
<td>1.37</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12.</td>
<td>Ormara, Pakistan</td>
<td>13.00</td>
<td>27.11.1945</td>
<td>MS 8.3</td>
<td>Arabian Sea</td>
</tr>
<tr>
<td>13.</td>
<td>Pasni, Pakistan</td>
<td>13.00</td>
<td></td>
<td></td>
<td>(24.5°N; 63°E)</td>
</tr>
<tr>
<td>14.</td>
<td>Victoria, Mahe Island, Seychelles</td>
<td>0.30</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15.</td>
<td>Not felt in India</td>
<td>--</td>
<td>19.08.1977</td>
<td>MS 8.1</td>
<td>West of Sumba Island, Indonesia</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(11.09°S; 118.46°W)</td>
</tr>
<tr>
<td></td>
<td>Cocos Islands, Australia</td>
<td>0.30</td>
<td>18.06.2000</td>
<td>MS 7.8 MW 7.9</td>
<td>Arabian Sea</td>
</tr>
</tbody>
</table>

Source: National Geophysical Data Centre, NOAA, USA  
(www.ngdc.noaa.gov/nmdc/servlet/ShowDatasets)

### 3. Earthquake of 26th December 2004:

On 26th December 2004, the Indian coastline experienced the most devastating tsunami in recorded history. The tsunami was triggered by an earthquake of magnitude Mw 9.3 at 3.316°N, 95.854°E off the coast of Sumatra in the Indonesian Archipelago at 06:29 hrs making it the most powerful in the world in the last 40 years. (Fig.1)

The earthquake of 26th December 2004 occurred off northwest of Sumatra is not an unusual earthquake from the Plate Tectonics point of view. It has occurred in the vicinity of seismically active zone, close to Sunda Trench in the water depths of about 1300 m. The earthquake hypocenter is located relatively at shallow depth, about 30 km below the ocean floor. The high magnitude, Mw 9.3 of the earthquake and its shallow epicenter have triggered tsunami in the northeast Indian Ocean. These were travelled in open ocean of the Bay of Bengal and subsequently transformed into a train of catastrophic oscillations on the sea surface close to coastal zones of Sri Lanka, east and west coasts of India.
3.1 Diving Indian plate

The earthquake of December 26 that occurred off the west coast of northern Sumatra took place at the interface between the Indian and Burma plates, where Burma plate has been referred by Andaman/Nicobar ridge that acts as a small tectonic plate (Curray et al., 1982). In this region, the Burma plate is characterized by significant strain partitioning due to oblique convergence of the India and Australia plates to the west and the Sunda and Eurasian plates to the east. It is a typical oceanic-oceanic convergent plate boundary where the Indian plate moving at a rate of 6 cm a year relative to the Burma plate came together, collided and the Indian plate dived (subducted) under the Burma plate. Volcanic eruptions are commonly seen at such convergent boundaries. "Two major plate tectonic features on either side of a narrow strip show how seismically active the region is."

3.2 Lethal combination

A lethal combination of huge magnitude and shallow depth focus led to high vertical displacement of the Burma plate that acted like a great piston deforming the sea. The aftershocks within two hours at the Andaman islands following the main earthquake in the Burma plate have gone further to fracture and move the Burma plate boundary by 1000 km. That in essence is the power of the earthquake that struck off the Sumatra coast. The U.S.Geological Survey has called this event a mega thrust earthquake referring to the large cracking of the plate boundary. According to them, mega thrust earthquakes often generate large tsunamis that can cause damage over a much wider area than is directly effected by ground shaking near the earthquake's rupture. Aftershocks are distributed along much of the shallow plate boundary between northern Sumatra (approximately 3°N) to near Andaman Island (at about 14°N).

Shallow focus earthquakes measuring 6.5 can also cause tsunamis. But such tsunamis will die out after some distance. The vast expanse of the Indian Ocean posed little challenge to the movement of the killer tsunami. Reaching a distance of 2000 km to hit the Indian coast was not difficult. Perhaps giant tsunamis can travel as far as 5000 km. This was the first time that a tsunami of this magnitude had struck the Indian coast.
Since a large amount of pent-up energy in the compression zones along the plate boundaries has been released in the recent earthquake of 26th December 2004, it will take years for another incident of the same magnitude to recur. But countries in the Indian Ocean should pay more attention to earthquakes and tsunamis in the future.

4 Observations of December 26, 2004 Tsunami in India

Tsunami was generated in the fast slip area (first 650 km at taut length) and the waves propagated in all directions. The propagation of tsunami waves is much
stronger in east-west direction than north-south direction. Further, due to slow slip in
the remaining northern areas, it appears that no tsunami was generated there. As a
result, strongest waves hit the coasts of Thailand, Indonesia and other nearby areas
which are closely located on the east of the epicenter. The intensity of these tsunami
waves that hit along the coastline of Orissa and Andhra Pradesh was weak due to
their diagonal propagation. However, southern east coast of India and Sri Lanka
experienced much stronger tsunami waves due to their location in mere western side
of epicenter. Though the Palk Strait and further southern areas of Tamilnadu are
shadowed by Sri Lanka, the waves refract around island and inundated these coastal
areas. The damage to Kerala coast on the west coast of India is also due to this
wave refraction beyond Kanyakumari.

4.1 Physical Observations

National Institute of Ocean Technology (NIOT), Chennai has deployed Acoustic Tide
Gauges (ATG) at selected places along the Indian coast and Port Blair. The tide
gauge at Port Blair, S.Andaman recorded gradual rise in water level by 0.9 m from
6.50 hrs to 7.01 hrs (compared to normal tide that would have prevailed) on 26th
December 2004 which might be due to land subsidence caused by the earthquake
(Fig. 2). At 7:25 hrs tide gauge showed abnormally high water level of 3.39 m, an
increase of water level by 1.0 m compared to level observed at 7.01 hrs indicating
arrival of Tsunami waves.

(Courtesy: NIOT, Chennai)

FIG 2. Variation of Tide at Port Blair during Tsunam
NIOT’s ATG at Chennai has also recorded the first signal of tsunami in the form of “receding water” at 09:06 hrs at Chennai Port Trust followed by abnormality in tide level at 09:15 hrs on 26th December 2004 (Fig.3). The tide gauge was overwhelmed by the sudden and abnormally high water level and harbour oscillations due to which the tide record showed a saturation at around 1.5 m. However, the lower ranges clearly show that the water level should have been much above 1.5 m. The difference between the time of occurrence of tsunami at Port Blair, Andaman and Chennai is around 2 hrs and corresponds well with the distance between Chennai and Port Blair and the speed of the tsunami wave.

The Tide gauge data from major Ports of India maintained by Survey of India has been processed by National Institute of Oceanography which showed that the tsunami hit Chennai at 09:06 hrs, Machillipatnam, Visakhapatnam and Paradip, at 09:05 hrs, Tuticorin at 09:57 hrs, along the east coast and on the west coast it hit Kochi at 11:10 hrs and Mormugao at 12:25 hrs (Fig.4). The non-tidal oscillations continued at Visakhapatnam, Tuticorin, Kochi and Mormugao well after the main event took place. NIOT’s ATG at Kochi has also recorded first hit of tsunami at 11:12 hrs coincided with that of Survey of India tide gauge.

There were no reports of inundation of coastal areas due to tsunami in the northern Andhra Pradesh and Orissa as the water level rose by less than 0.5 m. However, the inland areas like Ports and Harbours, for example, Visakhapatnam Fishing Harbour and Port experienced amplification of tide due to coning effect from outer harbour to entrance channel and unusual current speed in the order of 5 to 10 m/s (Fig.5).
FIG 4. Observed Tide at different Ports showing the sea level changes on December 26, 2004. Red arrow indicates the approximate time of occurrence of the earthquake off Sumatra and the blue arrow indicates the time of arrival of the disturbance at respective places. (Courtesy: Survey of India and NIO).
These strong flood and ebb currents have forcefully pulled 15-20 fishing boats out of harbour. During the course few boats encountered minor damage.

Although Tuticorin is situated south of Rameswaram, Tamilnadu, it witnessed tsunami at 09:57 hrs, almost an hour later it hit Chennai coast. It is to notice that when high energy tsunami waves traverse horizontally across Indian Ocean, the east coast of Sri Lanka has absorbed the devastating tsunami energy and the refracted waves with low energy only reached its west coast and southern east coast of Tamilnadu, which is confirmed by the wave modelling studies. Thus most of the southern coastal belt of Tamilnadu, shadowed by Sri Lanka, were less affected. It is for this reason, the refracted tsunami waves took more time to reach Tuticorin.
4.2 Extent of Inundation along Tamilnadu and Andaman & Nicobar Islands - observations by ICMAM-PD, DOD, Chennai

4.2.1 Chennai coast

A team of scientists from ICMAM-PD visited Besant Nagar Beach in Chennai immediately after hearing the first hit of tsunami to Chennai at 09:00 hrs and monitored the water level fluctuation from 10:00 hrs to 18:00 hrs on 26.12.2004 using sophisticated Real Time Kinematic GPS (Leica SR530, having accuracy of 1 cm for position and 15 cm for elevation) and DGPS (Leica GS5+) and analysed the impact of tsunamis.

At 09:00 hrs as the tsunami hit the Chennai coast, water excurred to a maximum of 200 m inside the beach (up to kerb wall of the beach) with a surge height of 2.5 m. Subsequently a series of waves hit the coast at 10:45 hrs, 12:30 hrs, 15:10 hrs and 17:10 hrs and the sea level returned to the original level around 18:30 hrs. At 14:50 hrs water line receded by 150 m from the original shore. The observations revealed that the run-up height at Chennai is about 3 m.

Elevation of beach/land and presence of sand dunes are controlling factors for water excretion and extent of damage caused by the waves. Marina beach, a few centimeter above mean sea level, experienced maximum inundation. About 1.8 km$^2$ of coastal area between Adyar and Cooum rivers along Chennai coast is inundated. The sea water excursed up to 590 m at Foreshore estate (Adyar river side) and 480 m at MGR memorial (Cooum river side) with a narrow excursion of 290 m at mid-stretch. The series of tsunami waves had a positive effect on Adyar and Cooum rivers, which are sewage carriers, whose mouths closed for most part of the year due to sand accretion, got opened, though temporarily, due to which these heavily polluted waters with sludge were flushed out to a great extent which might be having significant impact (but temporarily) on the water quality and biota of adjoining coastal environment. This can be clearly seen by the occurrence of bacteria up to or beyond 10 km offshore after tsunami when they were sighted at a maximum distance of 3 km offshore before tsunami at selected locations (Table 2).
TABLE 2. Distribution of Bacterial population before and after Tsunami along Tamilnadu coastal waters

<table>
<thead>
<tr>
<th>Bacteria</th>
<th>Before Tsunami</th>
<th>After Tsunami</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stations</td>
<td>Distance (km)*</td>
</tr>
<tr>
<td>THB (Max)</td>
<td>All stations</td>
<td>0.5, 1 &amp; 3</td>
</tr>
<tr>
<td>E.Coli &amp; Faecal coliform</td>
<td>All stations</td>
<td>Hot Spots &amp; 0.5</td>
</tr>
<tr>
<td>Salmonella LO (Max)</td>
<td>Tuticorin &amp; Chennai</td>
<td>0.5, 1 &amp; 3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bacteria</th>
<th>Before Tsunami</th>
<th>After Tsunami</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stations</td>
<td>Distance (km)*</td>
</tr>
<tr>
<td>SFLO (min)</td>
<td>Ennore coast</td>
<td>0.5 &amp; 1</td>
</tr>
<tr>
<td>Water/Sediment</td>
<td>All stations</td>
<td>Water low/ Sediment high</td>
</tr>
</tbody>
</table>

* distance from the coast.
(Source: CAS in Marine Biology, Parangipetalt)

4.2.2 North Chennai between Ennore and Pulicat

Observations made along the north Chennai coast indicated that the water level at Ennore creek rose by a maximum of 5 m and water excursed up to 300 m at the adjoining coast (Table 3). Though the Katupallikuppam fishermen settlement, located 6 km north of Ennore Port and 190 m away from the coast has escaped without any damage due to their occupation on a sand dune, the sea water inundated to about 500 m in low lying areas around the village (Fig.6). Further north, the Kalanji fishing hamlets were not affected by waves as the inundation is seen only up to 45 m.

TABLE 3 – Run-up level of sea water during tsunami at selected locations along Tamilnadu coasts

<table>
<thead>
<tr>
<th>Location</th>
<th>Max, run up level (m)</th>
<th>Distance of seawater inundation inland (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TAMILNADU COAST</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nagapattinam (Light House transect)</td>
<td>3.9</td>
<td>750</td>
</tr>
<tr>
<td>Chennai (Besant Nagar)</td>
<td>2.8</td>
<td>200</td>
</tr>
<tr>
<td>Chennai (Kattupalli)</td>
<td>1.8</td>
<td>190</td>
</tr>
<tr>
<td>Chennai (Kalanji)</td>
<td>1.4</td>
<td>45</td>
</tr>
<tr>
<td>Sathan Kuppam</td>
<td>3.5</td>
<td>80</td>
</tr>
</tbody>
</table>
Tsunami in one way benefited the Pulicat Lake by wide opening its mouth, but its fishing community, except a beach hamlet, is least affected due to presence of sand dunes. The above observations indicated that the extent of inundation decreased from Ennore to Kalanji due to the presence of shoals at north of Ennore Port, which acted as “wave dampers” in reduction of wave energy. Though this coastal belt is prone to accretion/erosion due to construction of Ennore Port, the ongoing studies of ICMAM-PD revealed that these shoals are acting as a natural barrier to the wave energy thereby controlling the intensity of erosion at north of Ennore Port. They also predicted that by considering the dimensions of these shoals, they may last for another few years. If the damage occurred to these shoals due to tsunami is significant, it will have considerable impact on the extent of their natural protection to this coast. In view of this, ICMAM-PD will soon undertake the monitoring of these shoals to ascertain the extent of damage to them due to tsunami.

Fig.6 Tsunami inundation map of Kattupalli village near Chennai
4.2.3 South of Chennai

The preliminary results indicated that the southern Chennai up to Mahabalipuram along east coast road has not been affected much due to steep land elevations and the maximum inundation is seen up to 250 m. Presence of sand dunes and plantations at most of the locations played a vital role in protection of coastal villages in this area. However in the Kalpakkam area where the Nuclear Power Plant is situated, the terrain is nearly flat and slightly elevated above mean sea level, greater inundation is seen in this zone.

Fig. 7 Inundation map of Cuddalore Old Town (Tamilnadu)

A death toll of about 500 is reported from the coastal area of Cuddalore with an inundation of 1 km at Devanampattinam coast mainly due to successive wave propagations through the backwaters (Fig.7). Severe damage is also noticed to fishing boats of this area. Further south of Cuddalore, the areas adjoined to the river mouths of Vellar, Chinna Vaikal (Pichavaram) and Coleroon were severely damaged claiming more than 1000 lives. The Parangipettai village (adjacent to Vellar river) witnessed maximum inundation up to 2.5 kms as the initial terrain slope (from coast) is very gentle and far reaching areas are low lying. The areas adjoined to Vellar inlet
and its backwaters which were marked as a green region with dense plantation acted as a barricade to tsunami waves which resulted in reduction of wave energy, otherwise the intensity of the damage could have been much more severe. The satellite images before and after tsunami of this region clearly explain this bio-shielding effect wherein the loss of vegetation after tsunami can be noticed (Fig. 8).

**FIG 8.** Loss of vegetation in and around Vellar inlet (in yellow circles) showing the bio-shielding effect to Tsunami waves.
The Vellar inlet which is having two openings each of about 290 and 235 m width as observed by a team of scientists from ICMAM-PD and IIT, Chennai on 24.12.04, a day before tsunami occurred was made opened to a great extent by tsunami waves resulting the seawater ingression up to 5 km inside. The satellite imageries of these mouth inlets before and after tsunami are presented in Figure 9. The flow of tidal waters inside the estuary has inundated the paddy fields with seawater.

![Satellite imageries before and after Tsunami showing the extent of opening to various inlets of Pichavaram area.](Courtesy: NRSA)

**FIG 9.** Satellite imageries before and after Tsunami showing the extent of opening to various inlets of Pichavaram area. (Source: NRSA)

### 4.2.4 At Nagapattinam

Nagapattinam, a coastal town, located about 400 km south of Chennai is the worst affected place in India due to tsunami claiming more than 6000 death toll and extensive damage to the public and private property. It is believed that the dual wave effect (straight waves plus diffracted waves from Sri Lankan coast), gentle slope of continental shelf and gentle elevation of hinterland coupled with the presence of Uppanar river and Vedaranyam canal in the southern side triggered the deadliest impact of tsunami waves. The preliminary observations revealed that the impact on the southern part is deadliest than northern part due to the presence of
these water bodies through which the successive progression of tsunami waves pushed the waters to distances beyond 1 km towards landside (Fig.10). However, the runup level in the northern part of Nagapattinam near Light House is close to 4 m with a maximum inundation up to 1.1 km from the coast.

FIG 10. Extent of inundation of seawater in Nagapattinam due to Tsunami.
Despite presence of wide beach (~200 m), the gentle land topography facilitated landward intrusion of seawater up to 1.1 km. Because of this, the high energetic waves crossed the beach and flooded the human settlement. Severe damage has been noticed to hundreds of fishing boats, several acres of agricultural land and also to beach tourism.

4.2.5. Tsunami in Andaman and Nicobar islands and observations on run up levels

The Andaman and Nicobar islands located in the subduction zone of Burma Plate is classified as Seismic zone 5 indicating high level of risks due to earthquake. Tsunami waves hit the Nicobar group of islands within few minutes and reached Port Blair in South Andaman at 7.25 hrs. The waves transformation varied at different locations (depending on the coastal geomorphology) and the tips of islands faced more fury of tsunami waves.

The Nicobar group of islands namely Great Nicobar, Katchall, Teressa, Nancowry, Trinkat, Car Nicobar etc. were severely affected by tsunami waves as they are closer to the tsunami and also smaller in nature surrounded by the sea all around. The impact on Andaman group of islands were less except on Little Andamans due to their remoteness to tsunami source and due to less intensity of tsunami waves. Since the settlement in South Andaman islands is largely confined in sheltered areas like bays and they are far from the coast and more importantly the settlement areas are in elevated areas except in certain low elevated far inland locations like Sippighat area, there were almost no loss of life, but damage to properties especially to fishing vessels were considerable. The extent of loss of life in A & N islands due to tsunami is given in Table 4.

Table 4. Death toll in A & N islands as of 23.1.05 due to Tsunami

<table>
<thead>
<tr>
<th>S. No</th>
<th>Islands</th>
<th>Population on (2001 census)</th>
<th>Dead</th>
<th>Missing</th>
<th>Persons in camp*</th>
</tr>
</thead>
<tbody>
<tr>
<td>NICOBAR DISTRICT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>Car Nicobar</td>
<td>20292</td>
<td>790</td>
<td>348</td>
<td>15550</td>
</tr>
<tr>
<td>2.</td>
<td>Teressa</td>
<td>2026</td>
<td>50</td>
<td>9</td>
<td>3296</td>
</tr>
<tr>
<td>3.</td>
<td>Katchal</td>
<td>5312</td>
<td>345</td>
<td>4310</td>
<td>1818</td>
</tr>
<tr>
<td>4.</td>
<td>Nancowry</td>
<td>927</td>
<td>1</td>
<td>2</td>
<td>934</td>
</tr>
<tr>
<td></td>
<td>Camorta</td>
<td>3412</td>
<td>51</td>
<td>387</td>
<td>1476</td>
</tr>
<tr>
<td>---</td>
<td>-----------------</td>
<td>------</td>
<td>----</td>
<td>-----</td>
<td>------</td>
</tr>
<tr>
<td>6.</td>
<td>Great Nicobar</td>
<td>7566</td>
<td>336</td>
<td>219</td>
<td>4690</td>
</tr>
<tr>
<td>7.</td>
<td>Other Islands of</td>
<td>2533</td>
<td>288</td>
<td>266</td>
<td>--</td>
</tr>
</tbody>
</table>

| Sub-total | 42068 | 1861 | 5541 | 27764 |

**ANDAMAN DISTRICT**

<table>
<thead>
<tr>
<th></th>
<th>Andaman includes, Port Blair</th>
<th>181949</th>
<th>5</th>
<th>--</th>
<th>2833</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.</td>
<td>Little Andaman</td>
<td>17528</td>
<td>56</td>
<td>14</td>
<td>6569</td>
</tr>
<tr>
<td>3.</td>
<td>Other Islands of Andaman</td>
<td>114607</td>
<td>3</td>
<td>--</td>
<td>5000</td>
</tr>
</tbody>
</table>

| Sub total | 314084 | 64  | 14 | 14402 |
| Total (UT) | 356152 | 1925| 5555| 42166 |

* includes persons from other affected islands.  
(Source: A & N Administration)

The inundation of seawater into the land with high velocity and their retreat with same or higher velocity cause extensive damage to human life and property. As said extent of inundation is measured in term of vertical run-up. The extent of vertical run-up of seawater depends on earthquake parameters, nearshore bathymetry, beach profile, land topography and velocity of tsunami waves and their frequency. Due to these parametric variations in Andaman and Nicobar islands, the run-up level and landward penetration characteristics of seawater varied from one location to the other within an island. The geometry of the islands and existence of offshore barriers like islets, trenches also play a role in the landward propagation of tsunami waves. Keeping these issues in mind and in order to get an idea on run-up levels, they were measured at a few selected locations which are considered to be representative. Due to logistics and other constraints, the measurements were restricted to north Andaman, Great Nicobar, Car Nicobar, Port Blair and Little Andamans.

A team of Scientists of Integrated Coastal and Marine Area Management (ICMAM) Project Directorate of Department of Ocean Development, Chennai assisted by Scientists from Andaman and Nicobar Centre for Ocean Science and Technology (ANCOST) of NIOT conducted run-up measurements in Andaman and Nicobar islands from January 18 - February 5, 2005. The locations were selected based on local enquiry. Elevations at clearly visible seawater mark on building/structures were taken as the Run-up levels for measurements. Table 5 gives the details of measured run-up levels which have been corrected to Mean Sea Level (approx. 0.8m
added to existing MSL to accommodate the land subsidence occurred during earthquake). Figure 11 shows locations at where inundation of run-up levels measurements were made.

![Figure 11 - Run-up levels (in meters) at selected locations in Andaman & Nicobar Islands (Names of locations are available in Table 1 against their run-up values)](image)

**Results and discussion**

In general, the extent of vertical run-up of seawater during tsunamis depends on earthquake parameters, geographical location, velocity of tsunami waves and their frequency, nearshore bathymetry, beach profile and land topography. Due to these parametric variations in Andaman and Nicobar Islands (A & N) and Tamilnadu coasts, the run-up levels and landward penetration characteristics of seawater were location specific and varied within a location and even in an island (Table 5). In the case of A & N, in the North and South Andaman group of islands the run up levels varied from 1.5 m to 4.5 m and the distance penetration from the coast ranged from 100 to 250m (Table 5). The little Andaman recorded a run up of 5 m with the distance of penetration 1200m. In the two Nicobar islands, the run up levels varied from 3 to 7 m with distance of penetration ranging from 50 to 1000m with higher run up levels and longer penetration noted in Car Nicobar (Table 5). Preliminary conclusions drawn by Bilham et.al. (2005) on the slip pattern of 26 Dec 2004 indicate...
that due to high rate of slip in the southern 650 km of the 1300 km North -South
rupture zone of 2004 Andaman-Sumatra earthquake, the principal tsunami was
generated in the Sumatra area. Time lag between earthquake and land subsidence
in Port Blair (S.Andaman) on 26 Dec 2004 which is estimated to be 30-38 min has
been interpreted as that the rate of slip was slow in the Andaman region resulting
generation of no tsunami in this zone. Therefore, the wide variation in the run up
levels between Andaman and Nicobar islands was primarily due to the remoteness
of North, Middle and South Andaman islands relative to Nicobar group to the tsunami
source zone and also due to nature of land topography in the run-up level
measurement locations. The wide variation between Andaman and Nicobar islands
was primarily due to the above said parameters and also due to land subsidence
caued by earthquake. Similar types of diversified results were observed in 26th
December 2004 Tsunami affected coastal areas in Indonesia and Srilanka. Run up
levels varying from 0.3 to 32 m were recorded in Indonesia and from 2.5 to 10 m in
Sri Lanka (Yalciner, et.al, 2005).

Table 5. Run-up level of sea water during tsunami at selected
locations in Andaman & Nicobar Islands

<table>
<thead>
<tr>
<th>Location</th>
<th>Max, run up level (m)</th>
<th>Distance of seawater inundation inland (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>South Andaman (Port Blair)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>J NRM College, Aberdeen</td>
<td>2.9</td>
<td>130</td>
</tr>
<tr>
<td>Bamboo Flat</td>
<td>3.5</td>
<td>250</td>
</tr>
<tr>
<td>New Wandoor</td>
<td>3.7</td>
<td>215</td>
</tr>
<tr>
<td>Wandoor</td>
<td>3.9</td>
<td>215</td>
</tr>
<tr>
<td>Chidiyatopu</td>
<td>4.5</td>
<td>130</td>
</tr>
<tr>
<td>Sippighat (Creek)</td>
<td>2.0</td>
<td>2000</td>
</tr>
<tr>
<td>North Andaman</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diglipur</td>
<td>1.5</td>
<td>100</td>
</tr>
<tr>
<td>Rangat</td>
<td>1.5</td>
<td>200</td>
</tr>
<tr>
<td>Little Andaman</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hut Bay</td>
<td>5.0</td>
<td>1200</td>
</tr>
<tr>
<td>Car Nicobar</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Malacca</td>
<td>7.0</td>
<td>1000</td>
</tr>
<tr>
<td>Great Nicobar</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Campbell Bay (central)</td>
<td>3.0</td>
<td>300</td>
</tr>
<tr>
<td>Campbell Bay (North)</td>
<td>6.0</td>
<td>50</td>
</tr>
</tbody>
</table>
Table 6. Coastal land slope values of various locations in Andaman and Nicobar Islands and Tamilnadu

<table>
<thead>
<tr>
<th>Location</th>
<th>Distance of seawater penetration (in metres)</th>
<th>Slope</th>
<th>Nature of Coastal land</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chidyatopu (South Andaman)</td>
<td>130</td>
<td>1 in 32</td>
<td>Short beach followed by steep elevated land</td>
</tr>
<tr>
<td>Hut Bay (Little Andaman)</td>
<td>1200</td>
<td>1 in 325</td>
<td>Low lying coastal land with gentle slope for long distance</td>
</tr>
<tr>
<td>Malacca (Car Nicobar)</td>
<td>1000</td>
<td>1 in 167</td>
<td>Gentle coastal land upto 800 m and steep rise beyond</td>
</tr>
<tr>
<td>Campell Bay (Great Nicobar)</td>
<td>300</td>
<td>1 in 89</td>
<td>Elevated beach followed by gentle slope of coastal land</td>
</tr>
</tbody>
</table>

The coastal land slope values were calculated based on RTKGPS data and these values are given in Table 6. The data indicates penetration of seawater to a short distance in Andaman islands (except Little Andaman) compared to the Nicobar group, which was the possibility of larger tsunami waves due to the presence of elevated areas within short distance from the coasts in the North, Middle and South Andaman. The little Andaman and the Car Nicobar islands that had relatively gentle slopes along the coast compared to the South Andaman island, experienced farthest penetration of seawater. The slope value of 1 in 32 for Chidyatopu in South Andaman compared to slope values of 1 in 325 for Little Andaman and 1 in 167 for Car Nicobar support this interpretation (Table 6). This clearly indicates the vulnerability of low lying areas with gentle beaches/land slopes to inundation of seawater during storms, tsunamis etc. The low lying areas adjoining the creeks which facilitate travel of tsunami waves far inland, are too vulnerable as indicated by the landward penetration of seawater upto 2 km from the creek in Sippighat area of Port Blair (Table 5).

Another major reason for inundation of seawater in South Andaman and Nicobar islands is land subsidence. Location specific interpretations made by ICMAM PD using the data of Andaman, Nicobar and Lakshadweep Harbour Works indicate subsidence of 0.8m around Port Blair and 1.3 m in Great Nicobar. Such a land subsidence is evident from the high tide water entering into the paddy fields of
Sippighat area that registered penetration of seawater up to 2 km during tsunami. Inundation of inland low lying areas during high tide has become a cause for concern to local population as their houses are marooned in seawater. The concern is likely to get aggravated during the monsoon months when the rain water antagonizes movement of high tide water. The net effect would depend on the velocity of rain water flowing from low lying areas through sluice gates to the adjoining bay. If the tidal force dominates, it may be possible that the rain water may accumulate in all low lying areas and both the freshwater and sea water would increase the height of water level and likely to spread to the neighbouring elevated areas too. However, atleast a full year observation is required to confirm this apprehension.

4.3 Run-up level and beach profile changes along Kerala coast - by CESS, Trivandrum

The December 26, 2004 tsunami had a devastating impact on the Kerala coast too. The locations of Kerala coast affected by the tsunami are shown in Figure 12.

![Fig 12. Locations of Kerala coast affected by Tsunami. The size of the circles indicates the relative severity of the damage](image)

Though this coast was in the shadow with respect to the direction of propagation of the tsunami waves, it had its access to the Kerala coast, obviously due to the processes of refraction, diffraction and reflection. Its destructive power left nearly
200 people killed and hundreds injured in addition to the loss of houses and properties worth several crores of rupees. The highest toll was reported from Kollam district followed by Alappuzha and Ernakulam districts. A large number of fishing boats and implements were washed away as tidal waves hit the coast. Hundreds of families had been shifted to relief camps as police, fire force and medical personnel swung into relief operations.

A team of Scientists from CESS, Trivandrum have conducted field visits all along the Kerala coast and estimated the run-up level along the shore and beach profile changes at the worst affected areas of the coast. For estimation of run-up level, the field signature such as trapped floating objects in plants/trees/buildings and information collected from local populace were relied upon. The beach profile and volume changes were measured for the worst affected regions of the Kollam and Alapuzha districts where the pre-tsunami beach profile changes were available.

4.3.1 Run-up level along the Coastal Zone of Kerala

The run-up levels for different stretches of Kerala coast are presented in Figures 13 - 15. The run-up levels given are with reference to the mean water level at each location. The southern zone between Thiruvananthapuram and Alappuzha had its most disastrous effect. Though the run-up level and inundation was less for Trivandrum coast it picked up towards north in the Kollam coast. North of Kovilthottam, there was a drastic increase in the level reaching as high as 5.0 m at Azhikkal, just south of the Kayamkulam inlet. This was the location where the inundation and loss of life and property was maximum. In the sector immediately to the north of Kayamkulam inlet also the run-up level was up to 5.0 m. The devastation here also was quite extensive, though not as much as at Azhikkal. The run-up levels in the central zone between Alapuzha and Kozhikode varied in the range 1.0 - 3.5 m (Figs.13 & 14). However, the northern zone run-up levels varied between 0.5 and 2.5 m (Fig.15). In Balathuruth, an island in Kadalundi river, near Kozhikode tsunami waves flooded the whole island and water level rose to 2 m high.
To sum-up, the run-up level distribution along the Kerala coast shows that it was least in the northernmost sectors encompassing the Kasargod district. The sectors adjoining the Kayamkulam inlet between Kollam and Alapuzha recorded the highest level of 5 m. Significantly flooding of only up to 2 m level occurred along the Thiruvananthapuram coast, which is close to Kolacheli, the location of maximum devastation along the west coast. It is summarised that the observed distribution of
run-up is caused by refraction, diffraction and reflection processes. The data collected may be very useful in the calibration of the tsunami inundation model to be set up for the coast.

FIG 14. Run-up level map for Kochi-Beypore sector of Central Kerala coast and Kozhikode region of Northern Kerala coast
4.3.2 Beach Profile variations and Volume Changes adjoining Kayamkulam inlet

Post-tsunami beach profiles were measured on 14\textsuperscript{th} January 2005 at 9 stations where pre-tsunami beach profiles (16\textsuperscript{th} November 2004) were available and where the reference stones were intact without any damage due to the tsunami. The stations for which profile changes were studied happens to be in the worst affected region surrounding the Kayamkulam inlet. This inlet has two breakwaters, north and south, jetting out into the sea for about three-fourth of a kilometer, as part of the Kayamkulam Fishing Harbour. The volume changes computed from the beach profiles are presented in Table 7.
TABLE 7. Volume changes at different stations adjoining the Kayamkulam inlet

<table>
<thead>
<tr>
<th>S.No</th>
<th>Station</th>
<th>Status</th>
<th>Volume change (m³/ m width of beach)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>N I</td>
<td>Erosion</td>
<td>53.4</td>
</tr>
<tr>
<td>2</td>
<td>N II</td>
<td>Erosion</td>
<td>16.1</td>
</tr>
<tr>
<td>3</td>
<td>N III</td>
<td>Erosion</td>
<td>66.5</td>
</tr>
<tr>
<td>4</td>
<td>N IV</td>
<td>Erosion</td>
<td>4.0</td>
</tr>
<tr>
<td>5</td>
<td>N V</td>
<td>Erosion</td>
<td>7.3</td>
</tr>
<tr>
<td>6</td>
<td>S I</td>
<td>Deposition</td>
<td>91.4</td>
</tr>
<tr>
<td>7</td>
<td>S II</td>
<td>Erosion</td>
<td>38.1</td>
</tr>
<tr>
<td>8</td>
<td>S III</td>
<td>Deposition</td>
<td>64.8</td>
</tr>
<tr>
<td>9</td>
<td>S IV</td>
<td>Deposition</td>
<td>12.6</td>
</tr>
</tbody>
</table>

It is seen from the Table 7 that erosion is seen in the northern side of breakwater (I I to N V), while deposition was mostly noticed in the southern side. The erosion/deposition obtained has to be seen in the backdrop of the coastal sedimentation processes prevalent in the area, in addition to the erosional impact of the tsunami waves. The breakwaters at the inlet, jetting out into the sea is acting as a groin, ever since the construction started a couple of years ago. Thus huge accretion has been taking place in the southern side of the inlet due to the predominant northerly longshore currents during fair weather. Erosion has been taking place in the northern side due to the groin effect of the breakwater. In the present case, the pre-tsunami beach profiles were taken on 14th November, 42 days prior to the tsunami onslaught. Thus the beach in the southern side of the inlet must have considerably accreted with respect to the pre-tsunami profile at the time of onslaught of the tsunami and thereafter till the post tsunami beach profiling on 14.1.2005. The field signatures on both the sides of the inlet showed scouring and erosion. However, the erosional effect of the tsunami was not sufficient enough to offset the depositional trend in the southern side except at station S II. In a similar way, the erosion observed in the northern side may not be entirely due to the tsunami.

Another point that has to be noted in the present case is that the erosion that took place due to the tsunami is not similar to the loss of sediment in the conventional sea-beach interaction where the sediment is lost to the sea. In the present case, the
eroded sediments might have been carried further inland and got deposited in the lagoon in the hinterland side.

4.4 Analysis of Oceansat OCM Data – by NRSA, Hyderabad:

The observation of sea surface temperature data showed the fall in temperature in coastal waters of Andaman and Nicobar waters up to 1°C on the day of tsunami. The tsunami had also an impact on the seawater turbidity as the successive waves churned the seabed and the reversal waves carried lot of land based wastes and soils resulting an increase in suspended particulate matter of the coastal waters as noticed from the satellite imageries between Chennai and Nellore coasts (Fig.16).

![Image of satellite imageries showing distribution of suspended sediment concentration before and after the tsunami event along Andhra Tamilnadu coast.](image)

**FIG 16. Distribution of Suspended sediment concentration before and after the tsunami event along Andhra Tamilnadu coast.**

The analysis of OCM data showed that suspended sediment concentrations have considerably increased along the Andhra and Tamilnadu coasts besides Andaman Islands after the tsunami event on 26 December 2004. The ranges of SSC are 9 - 21 mg/m³ on 25 December 2004 and 4-36 mg/m³ on 27 December 2004. Besides the increase in concentrations, the area of high SSCs had also increased from 15 km (50 m depth) to 45 km (1000 m depth) away form the north of Chennai coast. Though this is a temporary phenomenon as most of the sediment particles tend to be either dissipated towards offshore or settled to bottom, this might be having
significant effect on the marine biota. Inundation of sand spit near Kakinada, closer of inlet mouth and presence of a new channel near the Pulicat Lake are some of the important observations.

The effect of tsunami is also seen on chlorophyll concentration but is gradual compared to the SSCs. Chlorophyll concentrations on 25 and 31 December 2004 are shown in Figure 17. The increase in chlorophyll concentration from 0.1 to 0.3 mg/m$^3$ is clear from the figure. Since the chlorophyll is increasing gradually the analysis is continuing.

![Figure 17. Spatial distribution of Chlorophyll before and after Tsunami event.](image)

4.5 Impact of Tsunami on Biological Resources – by CAS in Marine Biology, Annamalai University, Parangipettai

The post tsunami survey made between Chennai and Nagapattinam was found to have variable results in terms of water quality, microbiology, plankton and benthos. In general the tsunami impact was found to alter the mouth region of the estuaries and backwaters. Equally the 5 and 10 km of the offshore waters also found to have more variations.

The sudden entry of tsunami waters into mouth of the rivers resulted in the release of more total nitrogen not only from the bottom derived tsunami waters but also the disturbances caused in the sediments of the mouth waters. Thus the Cooum river
waters of Chennai recorded the maximum total nitrogen of 165 µM in the water column, whereas the earlier observations before tsunami was only 90.6 µM. Similarly the Nagapattinam, Cuddalore and Parangipettai waters were found to record higher levels of nutrients at 0.5 and 1 km stretch coastal waters. In general the Karaikal coastal water was found to record fairly lower level of nutrients compared to other areas.

The microbial population was found to have only marginal differences between sediment and water column after tsunami. However, the sediment was found to record higher values in all the investigated areas compared to the water column. The Salmonella like organism was found to be recorded only in Nagapattinam and Chennai coastal stretches up to 10 km in the water, a unique feature after tsunami. Most of the forms were recorded more in the 0.5 and 1 km stretch was now recorded in the 5 and 10 km stretches (Table 2). This could be the post tsunami case for most of the coastal areas.

The blooming of phytoplankton Lauderia borealis (1,05,000-3,22,993 nos/l) was recorded only in coastal waters of in and around Chennai (Ennore, Cooum, Chennai harbour, Muttukadu). However, it is not recorded in other areas.

The occurrence of zooplankton pollution indicator species like Cesis sp., Lucifer and Oikopleura sp., is felt in parts of Tamilnadu and Pondicherry after tsunami. The distribution of zooplankton Cesis sp. was restricted to Cuddalore and Ennore coasts. The Lucifer having restricted distribution before tsunami is seen significantly all along Tamilnadu and Pondicherry coast after tsunami. The zooplankton Oikopleura sp was found to record higher (35,000/95,000 nos/m³) in the Tamilnadu and Pondicherry coastal waters, instead of restricted distribution in harbour waters.

In general very low numbers of benthic fauna (1-9/0.08 m²) and species (15) were recorded from Chennai to Nagapattinam coastal as well as the hot spot areas after tsunami survey. However, higher number (~146/0.08 m²) and diversity (35 species) were recorded at Cooum 0.5 km. Besides, the polychaete Polyodontes melanonotes (~2500/0.08 m²) was found to record only in Pondicherry hot spot area for first time.
The net impact of tsunami is that significant amount of nutrients were added to the coastal waters from terrestrial sources, mixing up of nutrient rich bottom waters, as well as from sediments which seems to trigger the biological production and leads to the promotion of chlorophyll levels. Added to this, the sewage mixed in coastal waters extended to distances even up to 10 km from shore which has promoted sewage feeding microbial organisms like E.coli, Faecal coliforms, Salmonella, etc. to these far off places when they were seen up to 3 km from coast before tsunami.

4.6 Ecological impact of Tsunami on the southwestern coast of Kerala and Tamilnadu - by RRL, Trivandrum

The coastal belt from Thottapally in Kerala to Kanyakumari in Tamil Nadu was monitored during January 2005. Transects were selected based on the basis of the intense impact of Tsunami. At each transect, stations were chosen at 5 km intervals, up to a distance of 25 km from shoreline. Water quality data after tsunami showed a slight deterioration at some of these transects (Table 9).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Kayamkulam Before</th>
<th>Kayamkulam After</th>
<th>Aleppey Before</th>
<th>Aleppey After</th>
<th>Vizhinjam Before</th>
<th>Vizhinjam After</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp (°C)</td>
<td>28.26</td>
<td>28.26</td>
<td>28.53</td>
<td>28.50</td>
<td>28.26</td>
<td>28.26</td>
</tr>
<tr>
<td>Salinity</td>
<td>33.24</td>
<td>33.62</td>
<td>33.54</td>
<td>33.75</td>
<td>33.24</td>
<td>33.82</td>
</tr>
<tr>
<td>pH</td>
<td>8.30</td>
<td>8.21</td>
<td>8.32</td>
<td>8.16</td>
<td>8.30</td>
<td>8.16</td>
</tr>
<tr>
<td>DO (mg/l)</td>
<td>5.67</td>
<td>4.84</td>
<td>5.61</td>
<td>5.85</td>
<td>3.16</td>
<td>4.69</td>
</tr>
<tr>
<td>NO₂ (µM)</td>
<td>1.69</td>
<td>0.18</td>
<td>0.13</td>
<td>0.38</td>
<td>0.04</td>
<td>1.69</td>
</tr>
<tr>
<td>NO₃ (µM)</td>
<td>3.22</td>
<td>3.25</td>
<td>--</td>
<td>3.88</td>
<td>1.29</td>
<td>4.25</td>
</tr>
<tr>
<td>SiO₄ (µM)</td>
<td>4.01</td>
<td>2.34</td>
<td>1.90</td>
<td>2.72</td>
<td>1.30</td>
<td>2.52</td>
</tr>
<tr>
<td>PO₄ (µM)</td>
<td>0.30</td>
<td>1.58</td>
<td>0.60</td>
<td>1.96</td>
<td>0.19</td>
<td>1.86</td>
</tr>
</tbody>
</table>

The post-tsunami results indicated that the marine environment in the southwest coast between Thottapally and Muttam has been affected as a result of the impact of tsunami. This is reflected by the following assessments:

- The concentrations of nutrients have decreased.
- Primary productivity has been drastically reduced.
The species diversity of plankton is lowered.
The fish catch is affected.
The microbial population has decreased.
The sediment samples collected offshore, have more of coarse sands, indicating their transportation from the coast.
The presence of heavy minerals in the sediment samples collected as far as 25 km offshore indicate that along with coarse sands these have also been transported due to high-energy backwash.
The impact of Tsunami was maximum at Vizhinjam due to the geomorphic feature resembling inland basin.

4.7 Coral reef ecosystems of Gulf of Mannar and Palk Bay - by Madurai Kamaraj University

Diving personnel of the Coral Reef Research and Monitoring group attached to the Center for Marine and Coastal Studies of Madurai Kamaraj University, made a rapid survey on the post-tsunami impact in selected islands of Gulf of Mannar and reef areas of Palk Bay on the northern side of Rameswaram and Mandapam.

The underwater surveys using Line Intercept Transect Method (LIT) revealed that there were no appreciable changes in the Bio-physical status of corals in the Gulf of Mannar. Coral species of the family Acroporidae which are vulnerable to the natural disturbances did not show any damage in their structures after the tsunami waves in the Gulf of Mannar. Also the massive corals and associated fishes, algae and sea grass beds were not affected by the tsunami waves. There was the slight displacement of the coral rubble walls lying near the edges on the seaward side of some of the islands of the Gulf of Mannar.

However, the survey of the corals of the Palk Bay region showed an increase in sedimentation near the coral reef areas after the incidence of tsunami waves. This is based on sediment traps already placed in several locations of the Palk Bay coral habitats for an ongoing research work. The sedimentation rate recorded earlier as 32.5 mg/d in November 2004 had increased to 53.4 mg/d after the incidence of tsunami tidal wave flushing in the Palk Bay region. Some corals exhibited partial bleaching near Pamban viaduct. Reports of people and fishermen in the region
confirmed that the water level raised up to 1 meter and then receded back to normal. There was no significant flooding in the nearby coastal areas.

As described earlier, the island nation of Sri Lanka has blocked and deflected the approaching tsunami waves and hence the coastal areas of the districts of Pudukottai, Ramanathapuram, Tuticorin and Tirunelveli were saved. Because of the deflection of the waves, the water had receded temporarily in some places before returning to normal. For instance the rocky bed which used to be always under water in Tiruchendur coast (near Tiruchendur temple) got exposed because of the receding water up to 50 meters from the normal low tide mark. Indications are that sediment load might have increased due to the sudden flushing effect of the tsunami waves and hence there is a need to make a complete survey of all the coral reef habitats around the chain of 21 islands in the Gulf of Mannar. The preliminary survey concluded that the impact of tsunami waves on either the corals or on the ecosystem was only minimal.

5. **Assessment of impact of tsunami in the Andaman & Nicobar and Bay of Bengal by Ocean going vessels of DOD**

The DOD’s vessels ORV Sagar Kanya and FORV Sagar Sampada were deployed for studying the impact of tsunami on the ocean environment and its resources in the Bay of Bengal and Arabian Sea during January – February 2005.

**ORV Sagar Kanya**

Immediately after the tsunami, the vessel PRV Sagar Kanya sailed from Goa on 3rd January 2005 with scientists from NCAOR, NIO, Goa and NIO, Regional Centre, Visakhapatnam and carried out multi-disciplinary observations along the affected coastal areas of Malabar coast and Nagapattinam, Cuddalore, Pondicherry and Chennai on the Coromandal coast. The vessel reached Chennai on 15th January 2005 and sailed for a cruise in Bay of Bengal and Andaman & Nicobar region, immediately. The vessel returned to Chennai on 21st February '05 after completing the 37-day post-tsunami cruise.
A 31-member team led by Dr K.S.R. Murthy, Scientist-in-charge of NIO RC, Visakhapatnam, comprising 9 Scientists from NCAOR, 8 from NIO, Goa and 7 from NIO, Regional Centre, Visakhapatnam, one from NPOL, Kochi, besides 6 from NORINCO, Chennai, participated in this cruise. The multi-disciplinary and multi-parameter data collection was so planned as to reoccupy some of the areas where earlier data were available and also to collect new data in some areas, which were not covered earlier.

**Preliminary observations made during the cruise in are given below:**

**Physical Parameters:** The sea surface temperature increased from 27°C off Chennai to 28°C at 92°40’ E. The mixed layer depth, which was inferred from temperature profiles, varied from 50 to 100m between 80° 52’ and 87°E and thereafter it decreased to 70m towards Andaman. A temperature maximum was observed at 84°E at ~80m. Along the west-east section, the near-surface salinity varied from 32.8 to 33.9 psu, with low salinity water (31.7psu) identified near the Andaman Islands. A conspicuous feature identified in the vertical profiles is the occurrence of high salinity core (35.2 psu) at 100 m between 83° and 84°E; in the same region the temperature maximum (~29°C) was also encountered. In general, surface freshening occurred near Andaman region.
Geophysics: The long-range profiles taken across the Bengal Fan following 10 and 13° N showed the characteristic bathymetry and gravity anomalies associated with the continental margin, the continent – ocean boundary (COB) and the deep sea Bengal basin, including 85° E and 90° E ridges. Towards the east, a sharp gravity low of the order of 124 m Gal was noticed over the Andaman Trench region. The Andaman fore-arc region was characterised by a broad gravity high of 122 mGal with a width of 150 km. This overall broad gravity high was associated with a series of highs and lows of the order of 20-25 mGals. These anomalies may be due to the presence of volcanic intrusions. In the back-arc basin, a distinguished regional feature was observed parallel to the Andaman Island chain between the latitudes 10° 30’N and 12° 30’N. The free-air gravity anomaly over this feature varied in amplitude between 150 and 75 mGals having a variable width of 70 km to 30 km. The Andaman Trench was characterised by a significant gravity low with broad gravity highs on both the sides due to Ninety-east ridge on the west and volcanic intrusions on the east, respectively. The irregular nature in the eastern side gravity high suggests a series of volcanic outpouring. The overall amplitude variation of the gravity anomaly over the trench area was from 60 to 100 mGals. Along 13° N the gravity anomaly was characterised by a high over the 90° E Ridge and a low over the 85° E Ridge. A detailed analysis of bathymetry, free-air and sub-bottom profiler data and its correlation with earlier geophysical data collected in this region will help us to demarcate any physiographic and tectonic changes that might have taken place in the Bengal Fan and Andaman and Nicobar regions, due to the earthquake. Chemical and biological parameters as well as sediment cores collected during the expedition are being analysed at the shore-based laboratories.

During the entire survey period in the Nicobar region, aftershocks of the Sumatra Earthquake of magnitude more than 5.0 have occurred at a fairly high frequency (at the rate of 2 to 3 per day). Plotting of the epicenters indicated that the area east of Katchal and Nancowry Islands was associated with more than 75 aftershocks forming a huge cluster around this part of the Nicobar Region, most of which occurred after 24th January, 2005. An interesting part of the cruise was that the cruise members experienced vibrations on the vessel for a few seconds on 24th January 2005, around 0946 hrs due to one such event of magnitude 6.3, with the epicenter located around 140 km SW of Katchal Islands. This epicenter position was confirmed by three
independent sources and the vessel was hardly 120 km east of this epicenter at the time of the event.

**FORV Sagar Sampada**

Leading scientists and media have raised apprehensions with regard to the impact of tsunami on the fishery resources also. In the given scenario, a team of scientists from Cochin University of Science & Technology, NIO-RC, Kochi, Annamalai University and CMLRE, Kochi sailed out from Kochi onboard FORV Sagar Sampada on 5.1.2005 to carry out detailed investigations on the impact of tsunami on the benthic communities, water chemistry and productivity patterns of the coastal waters covering Kerala, Tamil Nadu and Andhra coasts and Andaman and Nicobar Islands. Impact assessment was made through comparison of the results with previous data collected from these areas by the earlier cruises of FORV Sagar Sampada. Concurrent measurements on the near coastal waters i.e. up to 30 m depth were also undertaken by involving scientists from NIO-RC, Kochi; CUSAT; CMFRI, CMLRE and Annamalai University.

![Post-tsunami cruise track and sampling points of Sagar Sampada](image)

**FIG. 21** Post-tsunami cruise track and sampling points of Sagar Sampada
The observations made in the cruise on the Kochi – Chennai track during 05.01.2005 to 19/01/05, were:

- Sea surface temperature (SST) varied between 26.62° and 27.25° C. Mixed Layer Depth (MLD) ranged from 58 m to 82 m along the southeast coast.

- Except for silicate and phosphate values, all other chemical parameters viz. salinity, dissolved oxygen and pH were normal. Surface values of silicate were below 1.5µM. High phosphate values (up to 7.27µM) were observed at 30m and 50m stations off Nagapattinam, as against the normal values below 3.0µ M.

- Benthic organisms were recorded from all the stations. Study of major groups from samples collected from 30 m and 100 m depth and comparison with data earlier recorded during 1998-99 indicate that the major groups, which supported the number and the benthic biomass was not significantly affected. Since most of the organisms have a life span of one year or less, it is possible that even if there was a decrease in their numbers as noticed in the west coast, it was within the limit of recovery.

- Statistically sand and silt content variation was not found significant. A significant variation of clay particles in the east and west coasts at 30 and 100 m depths was recorded. The data indicate a substantial increase in the finer particles at 30 m depth at Kollam, Thiruvananthapuram and Kozhikode in the west coast and Chennai and Krishnampattinam in the east coast. At 100 m depth also an increase in finer particles was recorded off Kollam, Kochi and Kozhikode and in the east coast off Karaikal and Krishnampattinam. Statistically total sediment character change was significant at 30 and 100 m depth both in the east and west coasts.

- In the demersal fishery catches nothing unusual was observed. Neither algal blooms were observed, nor was abnormal swarming of zooplanktons noticed.

In the track of the tsunami from Andaman to Chennai (23/01/05 to 16/02/05) a number of observations were made. Both earthquake and the tsunami have affected the coastal regions of southern Andaman and Nicobar Islands. In the northeastern
region, the coastal area was not much affected as evidenced by the status of corals in the near shore waters. Corals, gorgonids and coral reef associated fauna were alive and in good condition in this region, indicating the stability of the bottom.

Even though the surface salinity and temperature didn’t show much variation in the middle Andaman, coral and associated fauna were heavily damaged in the Wandoor and Jolly boy region. This could be due to sedimentation and deposition of the debris over the coral reef beds by heavy force of tsunami waves and beach erosion.

Comparatively high values of nutrients concomitant with high dissolved oxygen promoted the phytoplankton production in the near shore waters of Viper Island and Minnie Bay, where the intensity of tsunami waves was high. A part of the beach was either submerged or eroded due to earthquake and tsunami.

In the fishing ground of northeast region, benthic organisms including sponges, gorgonids, echinoderms, etc, were alive and abundant, while in the southern region it was less but a large number of nautilus of various sizes was observed.

The areas having thick mangrove vegetation were least affected. In such areas beach erosion was very much reduced,

6 Inferences

The tsunami is an eye opener on set back lines decided for protection/conservation of coastal resources, beaches, protection of land, people, etc. Generally setback lines are decided in terms of distance from High Tide Line as done under the CRZ Notification. The run-up levels due to increase of sea level during tsunamis as well as during storm surges have added another dimension of elevation to be taken into consideration in the principle of setback line based coastal zone management. It is necessary to incorporate the elevation levels for new/expanded settlement areas under the Town and Country Planning Acts so that the human and property are saved from the natural hazards/vulnerabilities. The low lying areas like Nagapattinam, Nellore to Machilipatnam, Paradip to Bangladesh border, Kachchh coast in Gujarat, Andaman & Nicobar islands, etc. need immediate attention in this regard. Maps demarcating the extent of land areas vulnerable to seawater inundation
and safe locations for settlement, schools and vital infrastructure need to be prepared for all areas in the country. Where possible, the settlements and other human gathering locations like schools, theme parks, etc. need to be located at safer locations in a phased manner.

The fact of less damage to coastal villages located in elevated areas with wide beach front like Kalanji in north Chennai, mangroves shielding Killai village in Pichavaram mangrove have laid great importance for the need to protect beaches, mangroves, coral reefs, offshore shoals, etc. as they act as excellent natural barriers. It is necessary all developmental activities both existing and planned in the future need to adopt the construction codes stipulated for their region (for example, seismic codes for high risk zones like Andaman and Nicobar islands, Kachchh areas) and adopt best environmental practices to minimise loss or damage of natural barriers and to ensure protection of human life. The huge loss of human life (about 8000) in villages located close to the coast (like Keechankuppam, Akkaraipettai, Devanampattinam in Tamilnadu) amply demonstrate the vulnerability of human settlement located/occupied close to the coast, despite these areas had a beach front of 100-200 m.

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References


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General Information about Tsunami
- Internet