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Impact of December 2004 Tsunami on Indian Coasts and Mitigation Measures

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1. INTRODUCTION

Tsunamis are among the most terrifying natural hazards known to man and have been responsible for tremendous loss of life and property. For example, the Indian coastline experienced the most devastating tsunami in recorded history on 26 December 2004. The tsunami was triggered by an earthquake of magnitude 9.3 M_W at 3.316° N, 95.854° E off the coast of Sumatra in the Indonesian Archipelago at 06:29 hours making it most powerful in the world in the past 40 years (DOD, 2005; Rossetto et al., 2007). Though various natural hazards, viz., droughts, flash floods, cyclones, landslides, and snowstorms had caused great threats to the Indian subcontinent, tsunamis were rather unknown. Other dangers include frequent summer dust storms, which usually track from north to south and cause extensive property damage in North India. Many powerful cyclones, including the 1737 Calcutta cyclone, the 1970 Bhola cyclone and the 1991 Bangladesh cyclone have led to widespread devastation along parts of the eastern coast of India and neighboring Bangladesh (http://en.wikipedia.org/wiki/Natural_disasters_in_India). Widespread death and property destruction were reported each year in exposed coastal states such as Andhra Pradesh, Orissa, Tamil Nadu, and West Bengal. India's western coast, bordering the more placid Arabian Sea, experiences cyclones only rarely; cyclones mainly strike Gujarat and, less frequently, Kerala (http://en.wikipedia.org/wiki/Natural_disasters_in_India). Floods are the most common natural disaster in India. The heavy southwest monsoon rains cause rivers to distend their banks, flooding surrounding areas. Many of the above hazards are related to the climate of India and cause massive losses of Indian life and property.

Due to the destructive potential of tsunamis, they have notable impact on the social and economic sectors of our societies. Tsunamis can spawn when the sea floor abruptly deforms and vertically displaces the overlying water (DOD, 2005). There are three mechanisms responsible for such a deformation: (a) earthquakes with epicenters located below the ocean floor which can make the floor vibrate; (b) mudslides on the ocean floor, particularly on the continental slope, can suddenly change the shape of the ocean floor; and (c) volcanic explosions, either on the ocean floor or on the nearby continent, can lead to shaking of the floor, or during explosion huge quantities of ash that accompanies rapidly on the ocean floor. The above-mentioned perturbations of the ocean floor create a disturbance of the ocean surface, which then propagates as a shallow-water wave (Shetye, 2005). A wave becomes a shallow-water wave when the ratio between the water depth and its wavelength tends to be very small and the rate at which a wave loses its energy is inversely related to its wavelength.

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The intent of this chapter is to highlight the devastation caused by 2004 Tsunami along the Indian coasts and the major mitigation measures adopted thereafter. Firstly, an overview of various studies and surveys conducted related to 2004 Tsunami is presented followed by a brief discussion of the destructions caused by this tsunami in the shorelines of Kerala, Tamil Nadu, Andhra Pradesh, Pondicherry and Andaman and Nicobar Islands. Lastly, the rehabilitation measures implemented by the governments and various agencies of each state are discussed.

2. TSUNAMI: MECHANISMS AND HISTORICAL PERSPECTIVE

Tsunami is a series of waves created when a body of water, such as an ocean, is rapidly displaced. Earthquakes, mass movements above or below water, some volcanic eruptions and other underwater explosions, landslides, underwater earthquakes, large asteroid impacts and detonation of nuclear weapons at sea—all have the potential to generate a tsunami (http://en.wikipedia.org/wiki/Tsunami). "Tsunami" is originally a Japanese word, "*Tsu*" means *Harbour*, and "*Nami*" means *wave*. It is widely known only in the Pacific Ocean and occasionally seems to have occurred in the past in the Indian and Atlantic Oceans (Ramaswamy and Kumanan, 2005). These ferocious tsunami waves are formed as the displaced water mass, which acts under the influence of gravity, attempts to regain its equilibrium and the size of the resulting tsunami waves is determined by the quantum of the deformation of the sea floor. More the vertical displacement, greater will be the size of the waves. As a rule, all earthquakes do not produce tsunamis. When large areas of the sea floor elevate or subside, a tsunami can be created. Tsunami and tides both produce waves of water that move inland, but in the case of tsunami the inland movement of water is much greater and lasts for a longer period, giving the impression of an incredibly high tide. Tsunami has much smaller amplitude (wave height) offshore, and a very long wavelength (often hundreds of kilometers long), forming only a slight swell usually about 300 mm above the normal sea surface (http://en.wikipedia.org/wiki/Tsunami). A tsunami can occur at any state of the tide and even at low tide—will still inundate coastal areas if the incoming waves surge high enough. As the tsunami approaches the coast and the waters become shallow, the wave is compressed due to wave shoaling and its forward travel slows below 80 km/hour (http://en.wikipedia.org/wiki/Tsunami). Thus, tsunami can be defined as a catastrophic ocean wave, usually caused by a submarine earthquake, by an underwater or coastal landslide or by the eruption of a volcano (http://www.britannica.com/EBchecked/topic/607892/tsunami).

In the Pacific Ocean, 79 tsunamis were observed with 117 casualties but with extensive damages to properties. According to the Tsunami Laboratory in Novosibirsk, during the 101-year period from 1900 to 2001 (DOD, 2005), 796 tsunamis were observed or recorded. Nearly nine tsunamis caused widespread destruction throughout the Pacific. In the Indian Ocean, overall 63 tsunamis seem to have occurred between 1797 and 1977 AD and amongst which eight tsunamis have been triggered by earthquakes of magnitude more than 8 (Kumanan, 2005). Tsunamis generated in the Indian Ocean pose a great threat to all the countries of the region, viz., Indonesia, Thailand, India, Sri Lanka, Pakistan, Iran, Malaysia, Myanmar, Maldives, Somalia, Bangladesh, Kenya, Madagascar, Mauritius, Oman, Reunion Island (France), Seychelles, South Africa and Australia (DOD, 2005). The earthquake of magnitude 8.25 Richter Scale Units which occurred on 28 November 1945 near Karachi created large waves of height 11 to 11.5 m in the Kutch region. At 00:58 GMT on 26 December 2004, a massive earthquake of magnitude between 9.1 and 9.3 struck the coastal area off northern Sumatra in Indonesia. A number of aftershocks also occurred, some of magnitude 7.1. These earthquakes triggered tsunamis that affected Indonesia and neighboring countries in Asia (including India, Malaysia, Maldives, Sri Lanka, and Thailand) and the east coasts of Africa (including Somalia and Yemen) (Fig. 1), causing serious damage to the coastal areas and small islands (e.g., DOD, 2005; Rossetto et al., 2007; Srinivas and Nakagawa, 2007). Rossetto et al.

Fig. 1 Countries most affected (shown in red dots) by the 2004 Indian Ocean Tsunami (*Source:* Wikipedia, http://en.wikipedia.org/wiki/2004_Indian_Ocean_earthquake#Countries_affected).

(2007) summarize the observations of lifeline performance, building damage and its distribution, and the social and economic impacts of the tsunami made by the Earthquake Engineering Field Investigation Team (EEFIT) in Thailand and Sri Lanka (EEFIT, 2006). Australia and the countries of Europe had large numbers of citizens traveling in the region on holiday. Both Sweden and Germany lost over 500 citizens each in the disaster. The U.S. Geological Survey (USGS) initially recorded the toll as 283,100 killed, 14,100 missing, and 1,126,900 people displaced. However, more recent analysis compiled by the United Nations lists a total of 229,866 people lost, including 186,983 dead and 42,883 missing (USGS, 2005). The figure excludes 400 to 600 people who are believed to have perished in Myanmar, which is more than their government's official figure of only 61 dead. Measured in lives lost, this is one of the ten worst earthquakes in recorded history, as well as the single worst tsunami in history. The tsunami caused serious damage and deaths as far as the east coast of Africa, with the furthest recorded death due to the tsunami occurring at Rooi Els in South Africa, 8,000 km (4,971 miles) away from the epicentre (http://www.geocities.com/unsasdsu/africatsunami.html). In total, eight people in South Africa died due to abnormally high sea levels and waves.

In the case of India, the affected areas were limited in the geographical area as well as the extent of socioeconomic and environmental damage. The waves seriously affected the coastal districts of three states, Tamil Nadu, Andhra Pradesh and Kerala (http://en.wikipedia.org/wiki/Effect_of_the_2004_Indian_Ocean_earthquake_on_India). Among these states Tamil Nadu was the worst affected. The impact was huge in terms of human loss, natural resources and basic livelihood assets. Approximately 2,260 km of the coastal area (besides the entire Nicobar Islands) was affected and the fisheries sector bore the brunt of the tsunamis accounting for 85% of the damages. A tsunami run-up survey was taken up by the National Institute of Ocean Technology (NIOT) and ICMAM Project Directorate of Department of Ocean

Development, Chennai and the National Geophysical Research Institute, Hyderabad along the severely affected Tamil Nadu coast and the Andaman and Nicobar Islands (GSI, 2005). The survey concentrated on the maximum run-up heights and distances, average run-up heights and areas of inundation, flow patterns of run-up and run down, and recording of eyewitness accounts. The maximum tsunami run-up height is defined as the vertical water surface elevation reached by the tsunamis above sea level. It was measured using the standard surveying instrumentation. The survey results conclude that tsunami run up heights along Tamil Nadu, Kerala and Andaman & Nicobar Islands show variation of tsunami heights between 1.5 and 7 m. Most of the loss of lives and damage to property and infrastructure were generally observed within 100 m distance from the seashore. Large variations in tsunami inundation and associated loss of life and property were seen even within small differences in local run-up and coastal topography.

3. AN OVERVIEW OF THE STUDIES ON 2004 TSUNAMI

3.1 Studies Conducted in Foreign Countries

Using an integrated approach, tsunami affected land, vegetation and inhabitants were assessed by Mattsson et al. (2009) to evaluate the potential to restore and protect coastal land in the context of Kyoto Protocol's Clean Development Mechanism in Hambantota district in the south-eastern part of Sri Lanka. Firstly, assessments of the status of the tsunami-affected area were carried out by collecting soil and well water samplings for carbon and salinity analysis. Secondly, identification of potential tree species for carbon sequestration and sustainable development was conducted to determine carbon stock and suitability to grow under the prevailing conditions. In addition, interviews to understand the local people's perception of forest plantations and land use were conducted. The results showed that the resilience process of salt intruded lands from the 2004 Asian tsunami has progressed rapidly with low salinity level in the soils 14 months after the event, while the well water showed evidence of salinity contamination. Studies were conducted by Leclerc et al. (2008) for a better understanding of the mechanism of the aquifer contamination in the Ampara district of eastern Sri Lanka after the tsunami and to forecast evolution of groundwater conductivity with time. After the tsunami, it was observed that the salinity of the water inside the private wells used for drinking, bathing, washing or any household use was very high.

An article by Srinivas and Nakagawa (2007) emphasizes the cyclical interrelations between environments and disasters, by studying the findings and assessments of the Indian Ocean earthquake and tsunami of 26 December 2004. It specifically looks at four key affected countries namely Maldives, Sri Lanka, Indonesia, and Thailand and found that many of the activities associated with tourism, fisheries and agriculture sector of these countries will take many years to recover from the tsunami impacts. Tanaka et al. (2007) explored the effects of coastal vegetation on tsunami damage based on field observations carried out after the Indian Ocean tsunami on 26 December 2004. Study locations covered about 250 km (19 locations) on the southern coast of Sri Lanka and about 200 km (29 locations) on the Andaman coast of Thailand. Imamura (2004) introduced a new information system called TIMING (Tsunami Integrated Media Information Guide) for monitoring tsunamis in Japan for advanced and real time information. Papathoma et al. (2003) estimated the tsunami vulnerability for the Herakleio coast in Crete. Bandibas et al. (2003) developed new software – Geohazard View – for the interactive management of geological hazard maps. Jaffe and Gelfenbaum (2002) created geological records not only of a single tsunami but also the effects of past tsunamis. Walsh et al. (2000) compiled a tsunami hazard map based on the modeled inundation for the Southern Washington Coast. Minoura et al. (1994) studied the sediment deposited by tsunamis in the lacustrine sequence of the Sanriku Coast, Japan. Dawson (1994) found that the geomorphologic processes associated with tsunami run-up and backwashes are highly complex.

Tsunami hazard along the Morocco coast was evaluated by Alami and Tinti (1991) by comparing tsunami data with the set of available earthquake data.

3.2 Studies Conducted along Indian Coasts

A study conducted by Chidambaram et al. (2008) indicated that tsunami waves encroached the coastal ecosystem and changed the geomorphology, sediment characteristics and water quality of Tamil Nadu region. The area from Parangipettai to Pumpuhar was included in the study to assess the salinity variation due to the impact of tsunami. Significant variations were observed in apparent resistivity values, due to percolation of sea water into shallow aquifers. Changes in the formation resistivity and formation factor have also been noticed, which indicates salinity increase in aquifers. Babu et al. (2007) investigated the impact of tsunami on texture and mineralogy of a major placer deposit in southwest coast of India. Laluraj et al. (2007) made an attempt to assess the impacts of tsunami on the hydrochemistry of Cochin estuary and observed drastic changes in estuarine water quality (high saline, turbid, cool and nutrient-rich water mass) generated by the tsunami. Chandrasekar et al. (2006a) applied geospatial technologies to evaluate the impact of tsunamis on certain beaches in South India and compiled a hazard map. Kurian et al. (2006) investigated the inundation characteristics and geomorphologic changes resulting from the 26th December 2004 tsunami along the Kerala Coast, India. They noted that river inlets had been conducive to inundation; the devastation was extremely severe there, as the tsunami had coincided with the high tide. Chandrasekar et al. (2006b) reported that the extent of inundation depends mainly upon the nature of the coastal geomorphology. Sheth et al. (2006) found that the tsunami effects varied greatly across different parts of the coast according to the number of waves experienced, inundation distance and height of the waves, and density of the area; noted that the topological and geographical features were more vulnerable than others. The number of lives lost was also influenced by the proximity of habitats to the coastline, exposure to previous disasters, and the local disaster management capability.

Studies made by Srinivasulu et al. (2005) on the effect of tsunami on the sediments along Tamil Nadu coast indicated that the characteristics of Tsunami sediment deposits depend on the shelf sediments of the area. The maximum sediment inundation was observed in the Nagapattinam district of Tamil Nadu coast. Impact of the tsunami of 26th December 2004 on the coral reef environment of Gulf of Mannar and Pak bay in the southeast coast of India was studied by Kumaraguru et al. (2005). Raval (2005) reported severe destruction along the coast of Nagapattinam, South India, primarily because of its geographic setting, which has favoured much inundation. Narayan et al. (2005a) found that the elevated landmass (medu) played a key role in preventing inundation and minimising damage along the coast of Tamil Nadu. It was concluded that the width of continental shelf has played a major character in the pattern of tsunami damage. It was inferred that the width of the continental shelf and the interference of reflected waves from Sri Lanka and Maldives Islands with direct waves and receding waves were responsible for the intense damage in Nagapattinam and Kanyakumari districts, respectively. During the damage survey, it was also noted that there was almost no damage or much lesser damage to houses situated on or behind the medu. Presence of medu at Killinjal village, Nabiyarnagar and Nagapattinam Port reduced the damaging impact of tsunami on the built environment. The place of local increase of damage was dependent on river orientation and the path of tsunami. The southern part of Tamil Nadu from Kanyakumari to Pudukkottai District suffered least damage due to the presence of Sri Lanka in the passageway of tsunami.

Moreover, the level of damage in the Gulf of Mannar was more than that in the Palk Strait, since only diffracted waves were able to enter into the Palk Strait. Chandrasekar et al. (2005) and Mujabar et al. (2007) found that beach morphology and sediment volume along the southern Tamil Nadu coast were modified by the tsunami inundation. In recent years, advanced scientific techniques like GIS and remote sensing have been applied to comprehend and model various aspects of tsunamis. Mohan (2005) reported that the elevated coastal dunes and beach ridges along the coastline could act as barriers to minimize the rate of inundation along the northern parts of the Tamil Nadu coast. Narayan et al. (2005b) found that the degree of inundation was strongly scattered in direct relationship to the morphology of the seashore and run-up level on the Kerala coast.

Being one of the world's productive ecosystems, coral reefs are vital to the coastal populations. The post-tsunami status assessment of the islands and coral reefs around them in the Gulf of Mannar indicated that the margins and peripheral landscape of the islands were altered to certain extent (Kumaraguru et al., 2005). Corals of Shingle, Mulli, Van, Karaichilli and Vilanguchalli islands have been disturbed by the tsunami. Hence, it is imperative that their socio-economic role is taken into account and ecological measures implemented accordingly. The study proposes that developing a barrier reef ecosystem at least in the gulf of Mannar and Pak Bay regions would help boost the environmental, social and economic conditions of the coastal people. Further, Chandrasekar and Immanuel (2005) categorized the tsunami hazard for certain beaches of South India using GIS techniques. Keating et al. (2004) modeled the inundation of the Kealakipapa Valley, Hawaii, using a 10m-tsunami wave model.

4. IMPACT OF 2004 TSUNAMI ON INDIAN COASTS

The effects of 2004 Tsunami on Indian coasts are summarized in Table 1 and the details of the impacts are described in the subsequent sections by dividing the Indian coasts into three parts.

Table 1. Details of tsunami inundation on Indian coasts (Rasheed et al., 2006)

Details	*Kerala*	*Andhra Pradesh*	*Tamil Nadu*	*Pondicherry*	*A& N Island*	*Total*
Coastal length affected (km)	985	250	1000	25	NR	2260
Penetration of water into main land (km)	0.50-2.0	1-2	1-1.5	0.30-3.0	NR	-
Average height of the tidal wave (m)	5	3-5	7-10	10	NR	-
No. of villages affected	301	187	367	26	14 Islands	895
Dwelling units	1557	6280	85,878	6,403	NR	100318
Population affected (lakh)	2.11	24.70	6.72	0.43	1.83	35.79
Cattles lost	195	NR	5.58.2	3445	NR	9222
Cropped area (ha)	790	NR	2487	790	NR	4067

Note: NR = Not reported; 1 lakh = 100,000.

4.1 Southwest Coast

This covers Kerala, and the Kanyakumari district (Tamil Nadu), which suffered heavy loss of life due to human-created local topographical features. In Kerala, there is no documented evidence of any such events, although there are reports of some previous tsunamis (1881, 1833, 1941, to mention a few) generated by earthquakes in the Andaman-Sumatra region. A 1945 earthquake of M 8.0 in the Mekran coast is believed to have generated significant tsunami run-up in some parts of Gujarat, the only documented report of any tsunami affecting the west coast. To the best of our knowledge, the 2004 Tsunami is the first of its kind to have affected the Kerala coast. Although 2004 Tsunami affected the

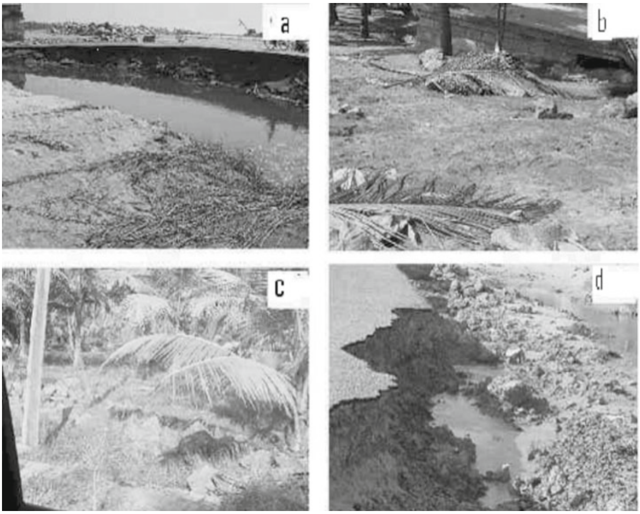

Fig. 2 Devastation caused by tsunami at Valiazhikkal region, north of Kayamkulam inlet and Edavanakkad, north of Cochin: **(a)** Deep trench formed close to the coastal road immediately to the north of Kayamkulam inlet; **(b)** Roof of a newly constructed house grounded due to wall collapse; **(c)** Boulders of sea walls thrown inland at Edavanakkad; and **(d)** Deep trench formed close to the coastal road at Edavanakkad (Kurian et al., 2006).

whole coastline of Kerala (Figs 2, 3 and 4), it devastated the low-lying coastal areas of Kollam, Alleppey and Ernakulam districts leading to the loss of life and property. In these districts, height of Tsunami waves varied from 1.9 to 5 m. The southernmost district of Thiruvananthpuram, however, escaped damage. This was possibly due to the wide turn of the diffracted waves at the peninsular tip, thereby missing Thiruvananthpuram (Sheth et al., 2006). Depending on the geographical orientation of the coast, geomorphology of the land mass, shallow water bathymetry and orientation of approaching waves etc., tsunami inundation and damage varies. Nearly 200 people were killed and hundreds injured in addition to the loss of houses and properties worth several crores of rupees. The coastal belt from Thottapally in Kerala to Kanyakumari in Tamil Nadu was monitored during 2005 January. Transects were selected on the basis of the intense impact of 2004 Tsunami. At each transect, stations were chosen at 5 km intervals, up to a distance of 25 km from shoreline. The water quality data after the 2004 Tsunami showed a slight deterioration at some of these transects.

4.1.1 Kerala

Ernakulam District: In Ernakulam district, maximum damage was suffered by Edavanakkad village, Kochi [Fig. 4 (a)], which is a prominent fishing center in Vypeen Island (about 20 km long and 3 km wide). It reports a loss of five lives, destruction of fifty houses and damaging of 350 houses. Damage due to the tsunami was more intense in the areas that were not protected by the seawall. At Edavanakkad, the seawall was about 100 m from the shoreline and was made of random loose rubble masonry comprising large boulders, some of which were displaced by the tsunami. The houses in Edavanakkad were built about 15 m from the seawall (Sheth et al., 2006).

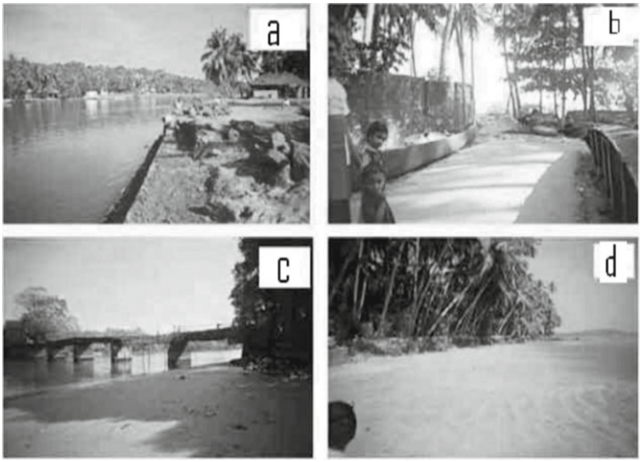

Fig. 3 Examples of tsunami inundation from northern Kerala: **(a)** Collapsed embankment at Choottad, Cannannore; **(b)** Country boats thrown inland at Kadalur point, Calicut; **(c)** Damaged railway footbridge at Thalassery; and **(d)** Collapsed laterite banks at Kadalur point, Calicut (Kurian et al., 2006).

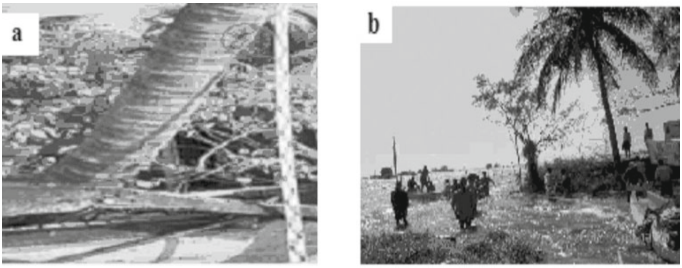

Fig. 4 **(a)** Run-up height of tsunami at Edavanakkadu; **(b)** Tsunami inundation at PuthuVypeen.

Allapuzha and Kollam Districts: The other strip most affected in Kerala is a shoestring cape south of the city of Allapuzha. It extends to 40 km long from Trikunnapuzha in the Allapuzha district to Karunagapalli in the Kollam district. The strip has a maximum width of less than 1 km and is bound by the open coast on the west and Kayanakulam Lake and backwaters on the east. A small opening in the strip connects the lake to the sea. The width of the land strip is less than 0.5 km at many places. As a result, the tsunami waves lashed over the entire strip of land, traveled across the backwaters, and rolled onto the opposite bank. Two areas that bore the brunt of the tsunami in the region were Arattupuzha in the Allapuzha district and the Alappad *panchayat* in the Kollam district. These areas are the gatekeepers of the opening where the lake disgorges into the sea. The villages are densely populated (with a density of 2,652 per km^2, versus the state average of 762 per km^2) on both sides of the coastal road that barely

Table 2. Comparison of water quality of selected coastal transects in Kerala before and after the 2004 Tsunami (Kurian et al., 2006)

Parameter	*Kayamkulam*		*Alleppey*		*Vizhinjam*	
	Before	*After*	*Before*	*After*	*Before*	*After*
Temp (°C)	28.26	28.26	28.53	28.50	28.26	28.26
Salinity (ppt)	33.24	33.62	33.54	33.75	33.24	33.82
pH	8.30	8.21	8.32	8.16	8.30	8.16
DO (mg/L)	5.67	4.84	5.61	5.85	3.16	4.69
NO_2 (µM)	1.69	0.18	0.13	0.38	0.04	1.69
NO_3 (µM)	3.22	3,25	-	3.88	1.29	4.25
SiO_4 (µM)	4.01	2.34	1.90	2.72	1.30	2.52
PO_4 (µM)	0.30	1.58	0.60	1.96	0.19	1.86

separates the lake from the sea. The isthmus has no intermediate bridge connected to the mainland and is linked to it only at the two ends. The area thus has to depend on boats for safe exit in times of emergency. The largest number of casualties (130) in Kerala was reported from the densely populated Alappad *panchayat* (including the villages of Cheriya Azhikkal and Azhikkal). In the village of Arattupuzha in the Allapuzha district, the death toll was 28. The seawall, where it existed, was dislodged and did not exist in many places along the north Kollam coast. A wave height of 4 m was reported by the survivors. The area has a history of floods that occur during the monsoon, especially when heavy rains coincide with high tide. The villagers are thus well trained in quick and safe evacuations, but there was no time for evacuation in these densely populated villages when the tsunami arrived. There was, however, no loss of life in villages such as Walia Azhikkal, where rapid evacuation was carried out successfully. After observations of abnormal behavior of the sea, the Kerala police had sounded an alert warning at 11:30 a.m. to caution people, but it was too late for some villages. The tsunami struck almost immediately afterward (Sheth et al., 2006).

The post-Tsunami results indicated that it affected the south west coast between Thottapally (Alleppey District) and Muttam (Ernakulam District). The concentration of nutrients, primary productivity and species diversity of plankton is lowered to a considerable extent. The population density of fish and microbes are reduced. The texture of the sediments changed into coarse sand with heavy minerals due to the high-energy backwash. The impact of Tsunami was maximum at Vizhinjam due to the geomorphic feature resembling inland basin. Construction of sea walls as a protection against tsunami does not seem to have any apparent merit. Edavanakkad (Ernakulam District), north of Cochin is a classical example where the sea wall, in spite of being well-built, was completely damaged with huge constituent boulders thrown far away inland (Kurian et al., 2006). Damage due to the tsunami was maximum in sectors adjoining Kayamkulam inlet in southern Kerala.

Measurements were made of land elevation, beach slope, tsunami flow direction and distance, maximum run-up height and duration of inundation, shoreline position and status of beach vegetation. Maximum intensity of the tsunami was observed in Kollam district followed by the districts of Alleppey and Ernakulam. The sectors adjacent to the Kayamkulam inlet between Kollam and Alleppey districts, recorded the maximum run-up height during the flood. The run-up level recorded at the northern side of inlet (Valiazheekkal) was 4.4 m. There was a drastic increase in the run-up level at Cheriazheekkal (southern side of inlet) and reached up to 5 m.

4.1.2 Tamil Nadu

The State of Tamil Nadu has been the worst affected on the main land, with a death toll of 7,793. Kanyakumari forms the southwest district of the State. Unlike the Kerala coast, the west coast of Tamil Nadu has flat land along the north coast in some areas such as Kolachel, where the soil is enriched with alluvium, but in other areas including further south, the land is mountainous. It slopes steeply upward from the coastline and is rocky. This was observed at Muttom Beach and at the tip of Kanyakumari. On some beaches such as Sothavilai, there are sand dune formations. Chandrasekhar et al. (2006) studied the impact of tsunami on the southern and western parts of Tamil Nadu including the districts of Kanyakumari and Tirunelveli. The results showed that the presence of Sri Lanka saved the beaches along the east coast from direct waves of high rapidity. Hence the beaches along the east coast are under least viability to any such similar hazards in future whereas high vulnerability prevails along the west coast beaches as they are devoid of any natural blockade (Narayana et al., 2005; Raval, 2005). The impact of tsunami rush was high in the southernmost part of the study area as most of the high vulnerable beaches falls on that region. They are Chinnamuttom, Kanyakumari, Manakudy and Pallam and are very much exposed to the refracted and diverted waves from Sri Lanka. Colachel suffered maximum destruction in the northwestern coast as the inundation has been encouraged by the river mouth. The impact was more in the beaches of low-lying flat topography as in the case of Manakudy and Colachel, etc.

Kanyakumari District: One of the most affected areas in the district was Kolachel and the surrounding villages, located 30 km west of Nagercoil, capital of the Kanyakumari district. The coastal area is flat at the sea level without any sea wall. Waves traveled inland by more than 300 m, which carved out new streams and estuaries. The town and neighboring villages recorded more than 500 fatalities, including half of them children. The wave height was reported to be 5 m, and the run up height was 2.6 m. A large number of deaths were triggered by the human created topology of this town. Harbour Road experienced the maximum number of casualties. A long (2.5 m deep and 6 m wide), open, dry channel called the Ananda Victoria Marthandam (AVM) Canal situated in the Harbour Road was meant to bring freshwater to this region. Besides, numerous open trenches were laid parallel to each other that catered to the special needs of the coir-making industry, which is the chief means of income in this region other than fishing. Tsunami waves made the canal and these trenches into death traps (Fig. 5). More than 300 bodies were recovered from the slush of the trenches and channel. The masonry retaining wall of the jetty at Kolachel was badly damaged. Muttom Beach, a popular tourist spot in Tamil Nadu frequently used as a romantic background by the Tamil film industry, did not suffer much damage, because it is more than 50 m above mean sea level. Tsunami wave, which arose at 10:30 a.m., washed away the tourists who came to see the beach. The Mannakudi *panchayat* near Kolachel, including Melamanakudi, was badly affected. A 160 m long bridge which connected the villages of Melamanakudi and Kelamanakudi on opposite banks of the Pazhyar River went missing after the tsunami. It was originally built with four spans out of which, the two end spans traveled upstream by 100 m and were beached on the banks; the central spans sunk into the waters (Fig. 6). Melamanakudi, a prosperous and scenic hilly village built on the waterfront, suffered complete damage. Structures 250 m from the shoreline suffered little or no damage, because the land sloped upward. About 150 people died at Melamanakudi. Sothavilai has a beautiful beach, which slopes upward from the shoreline and folds into sand dunes about 8-10 m high along parts of the beach. A beach resort has been constructed inland beyond the sand dunes. The tsunami waves lashed numerous teashops and other food stalls in the path leading to the beach causing loss of life and much scouring. An estimated 200 people, mainly stall owners and visitors, were victims. Kanyakumari experienced tsunami waves that were over 4.5 m high. Because Kanyakumari is on high land, the damage was limited—street furniture and compound walls were destroyed. About 1,200 people trapped at the rock memorial were successfully evacuated within a few hours of the incident.

Fig. 5 The AVM channel in Kolachel, which became a death trap; more than 300 bodies were found in the slush of the AVM channel and open trenches (Photo: Sheth et al., 2006).

Fig. 6 All spans of the Melamanakudi Bridge came off their bearings. The end spans drifted upstream, while the middle spans sank into the river (Photo: Sheth et al., 2006).

4.2 Southeast Coast

This includes the rich alluvial delta region of the Tamil Nadu coast and Pondicherry, which recorded the maximum loss of life and damage in mainland India.

4.2.1 Southeast Coast of Tamil Nadu and Pondicherry

The southeastern coastline of Tamil Nadu (800 km long) includes the Coromandel Coast in the north and the Fisheries Coast in the south. The coast north of Point Calimere up to Pondicherry was the worst affected region. It consists of the coastal districts of Nagapattinam, Cuddalore, Villipuram, Kanchipuram, and Chennai. The arrival of the first tsunami wave along the east coast coincided with high tide and amplified its effect. The coastline in this region is flat except for gentle slopes. From local residents, it was inferred that the beaches previously had a steeper slope than the present state. Many of the slopes and much of the vegetation have been cut during the last two decades to make way for coastal hamlets. The coastal districts of Tirunelveli, Tuticorin, Ramanathapuram, and Pudukkotai suffered relatively minor effects from tsunami waves. The tide gauge at Tuticorin Port, measured a wave height of nearly 1.8 m, which was only marginally higher than high-tide levels, partly because the tsunami waves were out of phase with the high tide.

In Chennai, besides seawater intrusion and deaths of numerous people, the impact also covers morphological changes along the coastline, where sea intruded in certain places and receded in others. In Adyar, the mouth of the river creek cut-off from the sea due to sandbar formation was cleared by big waves. The water quality of the area was affected due to increase in salinity and total dissolved solids along the tsunami-affected coast. A study was carried out in the tsunami-affected areas with respect to groundwater quality in the coastal areas of Adyar. The study area included Adayar and the surrounding areas in south Chennai that lie between latitudes 12°58′N and 13°08′N, and longitudes 80°16′E and 80°28′E (Palanivelu et al., 2006). Poor groundwater quality was evidenced in areas like Kottivakkam beach, Kuppam, Oorurolkot Kuppam (seashore), Raja Rangasamy Avenue (Thiruvanmaiyur), Foreshore Estate, Dhidir Nagar, Nochikuppam, Anna-MGR Memorial, which lie in close proximity to the sea and where sea water inundated during the tsunami. Apart from seawater-inundated areas, other areas showing poor water quality include R.A. Puram and Krishnamoorthy School, Adyar. Total Dissolved Solids (TDS) levels observed after the occurrence of the tsunami are within the range as observed during September 2004. Thus the recorded TDS values over time indicate that there is no major impact of the tsunami on water quality. As seepage of seawater is very less due to the short period of transgression during the tsunami, the aquifer has not been affected. Though seawater percolation into the ground through small pockets of waterlogged areas is possible, the effect would be less considering the short period of inundation of seawater during the tsunami. Thus it is clear that the groundwater quality has deteriorated due to lack of sufficient rainfall leading to seawater intrusion that is reflected in high TDS and chloride content of the analyzed samples.

Nagapattinam District: Nagapattinam District in Tamil Nadu was the most dreadfully affected territory within the entire mainland of India, where 6,051 fatalities were reported. Sujatha et al. (2008) studied the impact of tsunami waves on the sediments along the coastal belt of Nagapattinam. Sediments of the Nagapattinam beach, Tarangambadi temple, Tarangambadi temple site and Danish fort were analyzed for trace metals, total organic carbon, percentage carbon, hydrogen and nitrogen and nutrients (total phosphate, orthophosphate and exchangeable nitrate). The results show that the event has changed the chemical composition of the beach sediments and is threatening fishing grounds even in trace concentrations. Chromium showed the highest concentration at the Tarangambadi temple area compared to other stations. The Tarangambadi beach showed elevated concentrations of Nickel, Lead and Copper compared to other three stations. The variation of metal concentrations was drastic, due to the churning of the bottom sediments and their deposition along the shore by the waves, bringing changes in the beach profile and chemical concentrations. This remobilization contributes to environmental disturbance and is likely to have a far reaching effect on the life and activities of marine biota in general and pelagic fishery in particular.

Nagendra et al. (2005) studied the assemblages of foraminifera and its distribution pattern in the tsunami inundation areas of Nagappattinam coast. Samples were systematically collected from four locations (Nagappattinam (N), Kameshwaram (K), Vilundamavadi (V) and Velankanni (VK)) during the first week of January 2005. These locations experienced maximum inundation by tsunami waves. The foraminiferal assemblages recorded in the sediments brought by the tsunami waves were inferred to be derived from the shallow neritic zone along the Nagappattinam coast. Q-mode cluster analysis reveals that spatial variation of foraminiferal assemblage distribution and recognizes five biotopes along Nagappattinam coast. These changes in foraminiferal assemblage may be attributed to micro niches that control faunal distribution and also current circulation patterns along the coastal zones. The 200 m bathymetry of the continental shelf offshore east coast of Sri Lanka extends to Cuddalore-Nagapattinam sector along east coast of India, which might have channelized these waves to cause maximum damage in this part.

Velankanni: Velankanni, 12 km from Nagapattinam, where the Church of Mary, Mother of Good Health, a much admired pilgrimage center among believers for the healing powers is located. The central axis of the church is aligned with the main road leading to the beach. Thousands of worshippers had gathered in this town for Christmas, and many of them were at the beach on the morning of 26th December after attending mass. A tsunami wave approximately 5 m high first struck the shore at 9:20 a.m., followed by four more waves between 9:20 a.m. and 10 a.m. The waves inundated a distance of 900 m. The waves crashed onto the shore and continued on their rampage along the main road leading to the town. Though the water did not enter the church, it gushed up to the bus stand, inundating several shops and houses. A large number of bodies were found along this road. The inundation distance was more than 1,000 m (Sheth et al., 2006).

Seruthur: Seruthur is a coastal village adjacent to Velankanni. The height of Tsunami wave was the same as that of Velankanni. The number of deaths was lower due to: (i) lower population density, (ii) the base of the houses in this village was 1.5 m above ground level, and (iii) elevation of the ground was 1.5 m from sea level. The run-up height was 2 m above the plinth level, or 5 m above mean sea level. About 1000 boats and fishing trawlers were destroyed in Akkaraipettai, an important fishing port in the Nagapattinam district. Naliyanthottam, a godown storing gas cylinders was destroyed, with all cylinders being swept away by the tsunami. The godown was more than 800 m from the shoreline.

Nagore: Due to high elevation (more than 3 m from sea level), no serious damage was reported at the oil jetty at Chennai Petrol Chemicals Ltd. at Nagore. However, 1,200 houses were destroyed or damaged. Water entered almost 1,000 m inland. The rail link to Nagore, which is a pilgrim town, was cut off as a 7-km meter-gauge track between Nagapattinam and Nagore was completely damaged (Fig. 7).

Cuddalore District: Cuddalore was the second-most affected district and it borders Nagapattinam in the north. Silver Beach is a small amusement park developed for tourism and recreation activities, such as boating. Two rivers discharge into the sea at this scenic location. The first tsunami wave arrived at 8:35 a.m., with two subsequent waves within the next 15 minutes (Sheth et al., 2006). Almost three times as many women lost their life than men, with 391 female casualties, compared with 146 men. In Devanampattinam village in Cuddalore, for example, 42 women died compared with 21 men. In Pachaankuppam village, the only people to die were women (Sheth et al., 2006).

Kancheepuram District: Though the nuclear power plant at Kalpakkam in the Kancheepuram district was not affected by tsunami, the housing colony was very badly affected. The waves with a run up height of 1.5 m rushed into the colony damaging almost 1000 houses and the sea wall of 2 m high and 4 km

Fig. 7 Damaged railway line between Nagore and Nagapattinam in Tamil Nadu (Photo: Sheth et al., 2006).

long. Almost all courtyard walls of the houses for 1 km were collapsed. A school's compound wall was damaged, and electric poles were uprooted near the school grounds. The tsunami waves deposited a large quantity of sand near a pedestrian bridge.

Pondicherry: Pondicherry recorded 599 deaths. The damage was in two regions of Pondicherry—Karaikal and the city of Pondicherry. In Karaikal, the first tsunami wave struck the city at 8:45 a.m. and was followed by two more waves. The wave height was about 10 m and the run up height was 2.4 m. The damage was colossal in Karaikal- Nagapattinam stretch due to the flat topography of the region. In Kottuchery village located 5 km north of Karaikal town, the inundation was more than 1000 m. The compound wall of a self-financing Dental College was flattened. In Karaikal beach, which was situated in the estuary of Arasalar River, the damage was extensive. The road has been washed away. Several houses in fishing hamlet located were damaged (Ram Mohan, 2005). The run up was estimated to vary between 4 and 5 m. A settlement of 50 families of a fishing community called Karukalacheri was badly damaged. Pondicherry city, which lies north of Cuddalore district, experienced waves about 9 m but escaped relatively unscathed due to the stone seawall (height about 9 m above sea level) constructed almost three centuries ago. Although 107 bodies were recovered from Pondicherry and the surrounding hamlets, 56 of these bodies had been washed away from Tamil Nadu. About 25 people died on the Pondicherry promenade. They were fishermen living beyond the seawall boundary such as Kucchikupam, Ariyankuppam, Ponniyarpala, and Ganagachettikulam. At Kucchikupam, three waves washed out thatch huts, killed three people and damaged buildings with masonry brick walls. 16 people were reported dead at Ganagachettikulam, where people managed to build temporary houses within 10 days of the event.

4.2.2 Coast of Andhra Pradesh

The tsunami waves which struck the Andhra coast at about 9:05 a.m. brought about destruction to houses and loss of fertile land and employment. The waves penetrated about 0.2-1.0 km into the districts of Machalipatanam, Ongole and Kavali with an average wave height of 1.2-2.2 m. Comparatively less damage was reported at Srikakulam, Vishakhapatnam, Kakinada and Yanam (Pondicherry). Fishing and agriculture are the two dominant occupations in the villages along the coastline in Andhra Pradesh. The tsunami washed away most of the fertile topsoil and deposited heaps of sand, which ultimately left people with the choice of either changing the land use or changing the crop pattern.

Vishakhapatnam District: Vishakhapatnam, a very busy harbor and naval base, was protected by concrete tetrapods laid along the coastline. Vishakhapatnam Sea port and Vishakhapatnam Container terminal berths were empty on 26th December, so they suffered no serious damage. Vishakhapatnam Port had minor damage that created difficulty in navigational movements, cargo loading, and unloading. Fishing harbor boats and trawlers drifted away; 179 mechanized boats were partially damaged. The port suffered one full day's operational loss. Tsunami disrupted the fishing industry, many fishermen lost their boats and homes. It affected the sale of fish, which further destroyed the fishing industry.

East Godavari District: Sheth et al. (2006) have shown that East Godavari coastline suffered the least damage. The Kakinada Port Trust reported that some disruption in activities had disorganized its functions. The port was saved due to its peculiar shape and Hope Island acted like a shield. In this delta area, water channels or in some cases backwaters are extensively used to sail fishing boats right up to the edge of settlements. These channels helped to reduce the impact of tsunami water entering into the mainland. At Uppada village, however, the stone pitching of the embankment was damaged in some places. Studies by Mruthyunjaya Reddy et al. (2005) have shown that four villages were affected in the district. The seawater rose to 1-2 m, many boats and nets were damaged, but there was no damage to the houses.

Yanam and West Godavari Districts: Yanam has rich, black fertile soil deposited by the Godavari River. Paddy cultivation, high-quality brick manufacturing, ceramic tile molding, and fishing boat construction are some of the main occupations in Yanam. After the tsunami devastation, the two cottage industries of brick manufacturing and boat construction expanded rapidly. The soil is deep friable, well-drained sandy loam in the West Godavari district coastal belt. The land is a green mass of mangroves and a dense human-created forest of cash crops such as cashews, jackfruit, and coffee grown in the shade of coconut farms. The tsunami ruined the crops and replaced the standing cashew trees with sand deposits. Fresh ingress of water was seen in areas with dense mangroves. Part of the mangrove belt, in the path of the tsunami waves, was completely washed away, leaving another part partially or fully submerged in water for more than 48 hours. Silt had accumulated on the pneumatophores—the breathing roots of mangroves—choking the respiration of the mangroves. The tsunami left the area prone to further erosion of soil on seashores after the removal of vegetation cover. Slowly growing species such as mangroves, even if replanted, will take a long time to cover the entire land (Sheth et al., 2006).

4.3 Southwest Coast

Andaman and Nicobar Islands: Ramachandran et al. (2005) studied tsunami-induced damage to coastal ecosystems in four Nicobar Islands, viz. Camorta, Katchal, Nancowry and Trinkat. Tsunami-induced ecological damages are evident in all the four islands. There are damages to the structure and function of all the coastal ecosystems such as coral reefs, mangroves, sea grasses, estuarine mudflats, etc. The biological structure of the ecosystem could be easily disrupted as various species at different trophic levels were differentially removed, and with the structure altered, ecosystem functions could also be altered. Being a low-lying island, Trinkat has suffered maximum damage and has been cut into three pieces. The mangrove areas were affected to the extent of 335.70 ha (51%) in Camorta, 339.03 ha (69%) in Katchal, 152.53 ha (100%) in Nancowry and 240.06 ha (68%) in Trinkat. Such a major damage in mangrove area will severely affect the coastal productivity and destabilize coastal areas, which will accelerate shoreline erosion and increasingly affect the forest area due to salt-water intrusion into the forests. Extensive damage to coral reef is seen in all the four islands. The extent of reef area affected is

Table 3. Extent of area affected by the tsunami in the Andaman & Nicobar Islands (Ramachandran et al., 2005)

Class	*21st December 2004*	*4th January 2005*	*Change in area (ha)*	*Percentage change in area*
Camorta Island				
Mangroves	651.94	316.24	335.70	51
Plantation	4509.44	4147.02	-362.42	-8
Reserved Forest	8311.73	7771.42	-540.31	-7
Sand	356.49	725.21	+368.72	+103
Settlements	32.82	27.04	-5.78	-17
Mud over reef	733.24	896.93	+163.69	+22
Reef area	1775.12	1035.97	-739.15	-41
Water logged area	-	283.12	-	-
Katchan Island				
Mangroves	576.37	177.34	-399.03	-69
Reserved Forest	9801.72	8014.72	-1787.00	-18
Sand	473.82	1715.84	+1242.02	+262
Reef area	548.48	-	-	-
Water logged area	-	1640.60	-	-
Settlements	340.52	222.85	-117.67	-35
Nancowry Island				
Mangroves	152.53	0.00	-152.53	-100
Plantation	244.32	176.26	-68.06	-27
Reserved Forest	4212.49	4064.36	-148.13	-3
Settlements	25.42	-	-	-
Sand	254.32	175.34	-78.98	-31
Reef area	829.13	381.98	-447.14	-53
Mud flat	106.39	-	-	-
Water logged area	-	91.07	-	-
Trinkat Island				
Mangroves	352.93	112.33	-240.60	-68
Plantation	649.10	644.57	-4.53	-1
Reserved Forest	561.58	419.09	-142.49	-25
Sand	195.38	214.08	+18.70	+10
Settlements	71.52	30.09	-41.43	-58
Reef area	2432.12	986.47	-1445.65	-59
Mud over reef	-	440.01	-	-
Turbid water	-	552.44	-	-
Water logged area	-	126.89	-	-

41% at Camorta, 49% at Katchal, 53% at Nancowry and 59% at Trinkat. The sandy areas have considerably increased in two of the four islands. The increase in the extent of sandy beaches after the tsunami was 18.7 ha in Trinkat and 1242.02 ha in Katchal, whereas decrease in sand cover is witnessed in Camorta 368.72 ha (103.43%) and Nancowry 78.98 ha (31%).

5. REHABILITATION AND MITIGATION MEASURES ADOPTED BY THE LOCAL GOVERNMENT AGENCIES AND NGOs

In Kerala, the cooperative federation called Matsyafed undertook the rehabilitation measures in the coastal areas devastated by tsunami (Salagrama, 2006). The state government provided Rs. 134.86 crores for replacing and repairing damaged fishing implements. In the NGO sector, many agencies provided boat engines, and net to the fishers, mostly on a group ownership basis. Other mitigation measures included introducing self-help groups among women, giving assistance for small business in several areas and helping the youth in taking up alternate employment in construction and other sectors. Kurian et al. (2006) observed that shore protection systems (such as sea walls) and coastal engineering structures had variable impact on inundation along the Kerala coast. For example, the sea walls could control tsunami waves to some extent at Thangassery and Neendakara, as it was not so at Edavanakkad coast. Also, the presence of backwater at the Kayamkulam inlet increased the inundation along this coast. From these observations, it can be concluded that no single measure or uniform strategy is viable in mitigating tsunami-caused coastal hazards.

Foodstuff, garments and other provisions were brought to the camps in abundance from all quarters. The government offered medical assistance by the end of January 2005. All the affected people had moved to temporary shelters by the end of April. The government declared a grant of Rs. 7500.00 to all families moving into houses of their own choice and Rs. 3500 to all families moving into government built temporary shelters (SIFFS, 2005). Temporary shelters for tsunami victims who lost their houses were constructed by the government in four clusters in the tsunami affected wards of Alappad. Cheriazheekal, Srayikkadu, Aiyramthengu and the fishing harbor in the banks of the Kayamkulam lake estuary in Azheekal were the sites chosen for the shelters in Alappad. In Kollam district, 2969 houses were allotted to the affected people and 40 acres of land was acquired by the government for the relocation of affected families. Government has sanctioned Rs. 1.084 crores for the construction of sea wall in Alappad and Rs. 225.786 lakhs worth of free rations to the affected people. Kerala Water Authority spent Rs. 15.91 crores for various water supply works in Kollam district. Non-governmental organizations like Seva Bharati, the Quilon Social Service Society and Sahayi, working in the affected areas have built thatched (coconut palm frond) shelters with a small kitchen attached, for people (land owners) who opted for their own accommodation (SIFFS, 2005). Other non-governmental agencies involved in tsunami rehabilitation throughout the state include Kerala Voluntary Health Service, Kerala Vyapari Vyavasai Ekopana Samiti, Mata Amritanandamayi Math, Nehru Yuva Kendra, etc.

In Alappuzha district, Rs. 1.69 crores were spent for the relocation of those who lost their houses in the tsunami. Kerala Water Authority spent Rs. 8.28 crores for the construction of the sea wall, and Rs. 2.19 crores for the laying and repair of roads in the affected areas. The KSEB has done a line extension in Arattupuzha for Rs. 3.24 crores (SIFFS, 2005). Many fishermen have been given fishing boat, engine and nets by various agencies. Many stake nets and Chinese dip nets on the Kayamkulam estuary were washed away by the tsunami. The government has announced compensation for the Chinese dip nets but the environmentally harmful stake nets have not been compensated to date. Compensations for other indemnity suffered to fishing craft and gear in the inland sector have also been declared. The non-governmental agencies of the state organized different programs for the people, especially the children in the rehabilitation camps.

The main tsunami effects in Tamil Nadu related to marine fisheries included loss or damage to fishing boats, nets and engines; infrastructure for landing, fish processing and trade related activities, apart from loss of lives of active fishermen. The tragedy has invoked instant response from all government bodies, non-government organizations, celebrities, and corporate and international organizations (Salagrama, 2006). In Tamil Nadu, government introduced a package for replacing fishing nets for vallams and catamarans. Assistance was given to repair engines and damaged boats and catamarans and for obtaining bank loans at subsidized rates for the reconstruction. Government provided monetary assistance to the fishers, exempted payment of sales tax for purchase of goods necessary for reconstruction. Government also provided assistance to aquaculture owners, fish transporters and ice manufacturers and made arrangements for repairing fishing harbors, jetties and landing centers. According to Ghouse (2005), mitigation strategies in Tamil Nadu included agri-engineering based immediate, short-term and long-term strategies to bring back the soil, agriculture, horticulture, forestry, groundwater etc. to normalcy.

Andhra Pradesh government put up an institutional framework to offer support to affected people. The World Bank-aided Andhra Pradesh Rural Livelihood Program (Velugu) was the nodal agency for rehabilitation of the Tsunami affected fishing communities in the state. Velugu made arrangements for the repair of damaged boats, and the replacement of fully damaged boats by new boats, as well as provided loan for new boats, and replaced nets and other fishing gears (Salagrama, 2006). Sonak et al. (2007) documents several issues involved in the recovery of tsunami-affected areas and recommends the application of the ICZM (Integrated Coastal Zone Management) concept to the reconstruction efforts. The concept of ICZM has been effectively used in most parts of the world. This concept emphasizes the holistic assessment of coasts and a multidisciplinary analysis using participatory processes. It integrates anthropocentric and eco-centric approaches. Xue et al. (2004) notes that the World Bank (2002) views ICZM as a "*process of governance that consists of the legal and institutional framework necessary to ensure that development and management plans for costal zones are integrated with environmental and social goals, and are developed with the participation of those affected*". ICZM is an accepted management framework to address coastal and marine environmental problems and conflicts, and to achieve sustainable use of coastal resources in developing countries.

6. TSUNAMI DISASTER REDUCTION AND PREPAREDNESS

India has witnessed some major disasters in recent memory and the lack of preparedness and inadequacy to face such calamities has been apparently visible. The Indian Ocean tsunami of 26 December 2004 was a disaster of unprecedented magnitude. Across the 12 affected countries in Asia and Africa, more than 230,000 people were reported dead or missing, over 2.1 million were displaced and left homeless, and millions of dollars of infrastructure was destroyed. The scale of the devastation presented enormous challenges for disaster response in the context of the evolving concept of disaster management (NDM, 2005). State governments have limited resources and infrastructure facilities to handle a major disaster. We know that natural hazards cannot be controlled. However, the vulnerability to these hazards can be reduced by planned mitigation and preparedness measures. There needs to be concerted and sustained steps towards reducing the vulnerability of communities to disasters. The past couple of years have witnessed a paradigm shift in the approach of central and state governments towards disaster management. The new approach proceeds from the conviction that development cannot be sustainable unless disaster mitigation is built into the development process. Another corner stone of the approach is that mitigation has to be multi-disciplinary spanning across all sectors of development.

Disaster management involves three phases—**pre-disaster**, **during the disaster**, and **post-disaster**. The pre-disaster phase consists of *risk identification*, *mitigation*, and *preparedness*. During the disaster, *emergency response* takes place, and in the post-disaster phase, *rehabilitation* and *reconstruction* are applied. The national government has set up a National Disaster Management Authority, with Prime Minister as its chairman. In the meanwhile, the Government has established a nodal agency (Delhi Disaster Management Authority) to facilitate, coordinate and monitor disaster management activities and promote good disaster management and mitigation practices in the state (http://www.ndmindia.nic.in/Mitigation/mitigationhome.html). Two Working Groups for (i) Prevention and mitigation and

(ii) Preparedness and response have been constituted and notified. These groups further consist of sub-groups to deal with awareness generation, capacity building, planning, techno-legal aspects, etc. In order to make the awareness generation activities more effective, the Government has developed a lot of resource material comprising leaflets, posters, planning documents, earthquake tips, etc. for wide dissemination. The IEC material serves as an agent to generate awareness and induce mitigation and preparedness measures for risk reduction. Multi-media CDs on disasters developed by various government agencies have been distributed in selected states of India. The efforts of the national government to introduce disaster management as a compulsory paper in all fields of study at graduation level in all the states of India, if and when realized, will ensure sustainable disaster awareness among the youth, leading to disaster risk reduction in due course.

7. CONCLUSIONS

In this chapter, a review of damages caused by the 2004 Tsunami disaster in the shorelines of India has been presented, together with the rehabilitation and mitigation measures taken by the local/national authorities. In addition, the plans and measures adopted by the Government of India for reducing tsunami disaster risk in the future are also highlighted in this chapter. In India, states of Tamil Nadu, Kerala, parts of Andhra Pradesh, Union Territory of Pondicherry and Andaman and Nicobar Islands witnessed the worst impacts of 2004 Tsunami on social, economic and ecological systems. It is evident that low-lying coasts were the prime victims of the tsunami surge, as they were unable to put up any resistance against the accelerating tsunami surge. Although the overall impact of the tsunami on the east coast was severe, damage to coastal protection structures was limited. Maximum damage observed along the coast of Nagapattinam district (Tamil Nadu) may be due to the lesser width of continental shelf and the interference of direct waves with the reflected waves from Sri Lanka. As an immediate measure, the state governments released funds for the treatment of those seriously injured in the tsunami and distributed free rations to the affected people. NGOs provided temporary shelters to all those who lost their houses and livelihoods. Governments and other social service societies made provision for replacing fishing equipments damaged in the tsunami and for the reconstruction of fishing harbors.

The 2004 Indian Ocean tsunami event allowed the assessment of technological approaches for disaster management. These approaches include GIS, GPS, RS, modeling, etc. Geographic Information System (GIS) facilitates common database operations with unique means of visualization and analysis. It assists users in statistical analysis and provides a base for interpreting how physical, social and economic factors interact in space. Global Positioning System (GPS) is a satellite-based positioning system for capturing locations of sample points, which can be used to reference satellite images or other spatial data layers. Further, Remote Sensing (RS) provides images of the earth's surface, which enable the classification of different types of land cover and the monitoring of land cover/land use change. High temporal resolution of some satellites has made remote sensing—in combination with GIS—an extremely useful tool for rapid mapping in support of disaster relief, as was the case during the tsunami in South-East Asia in December 2004. Furthermore, Tsunami Warning System is based on the concept that tsunamis travel at a much slower velocity (500 to 700 km/h) as compared to seismic waves (6 to 8 km/s). That is, the seismic waves move 30 to 40 times faster than the tsunami waves. Hence, after the occurrence of a damaging earthquake and quick determination of epicenter, warning time of a few minutes to 2 to 3 hours is available depending upon the distance from the epicenter to the coast line. This time can be utilized for warning the coastal community if quick detection and rapid communication systems are established. Thus, the geospatial technologies (GIS, GPS and RS), modeling techniques and Tsunami Early Warning System are promising tools for reducing the risk of tsunami disasters and developing effective disaster management plans.

Finally, actions related to reconstruction and recovery of tsunami hazards should ensure that the sustainability of coastal and marine ecosystems is not compromised, and is ideally enhanced as the goods and services they provide strengthen the livelihoods and immediate welfare of large coastal populations. A comprehensive coastal zone management strategy is required to reflect livelihood needs, reduce vulnerability to natural hazards, and the conservation of biodiversity and ecological services. Economic, environmental, social and cultural factors must all be taken into account when developing disaster risk mitigation strategies and solutions must be anchored in the prevailing circumstances of local situations.

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