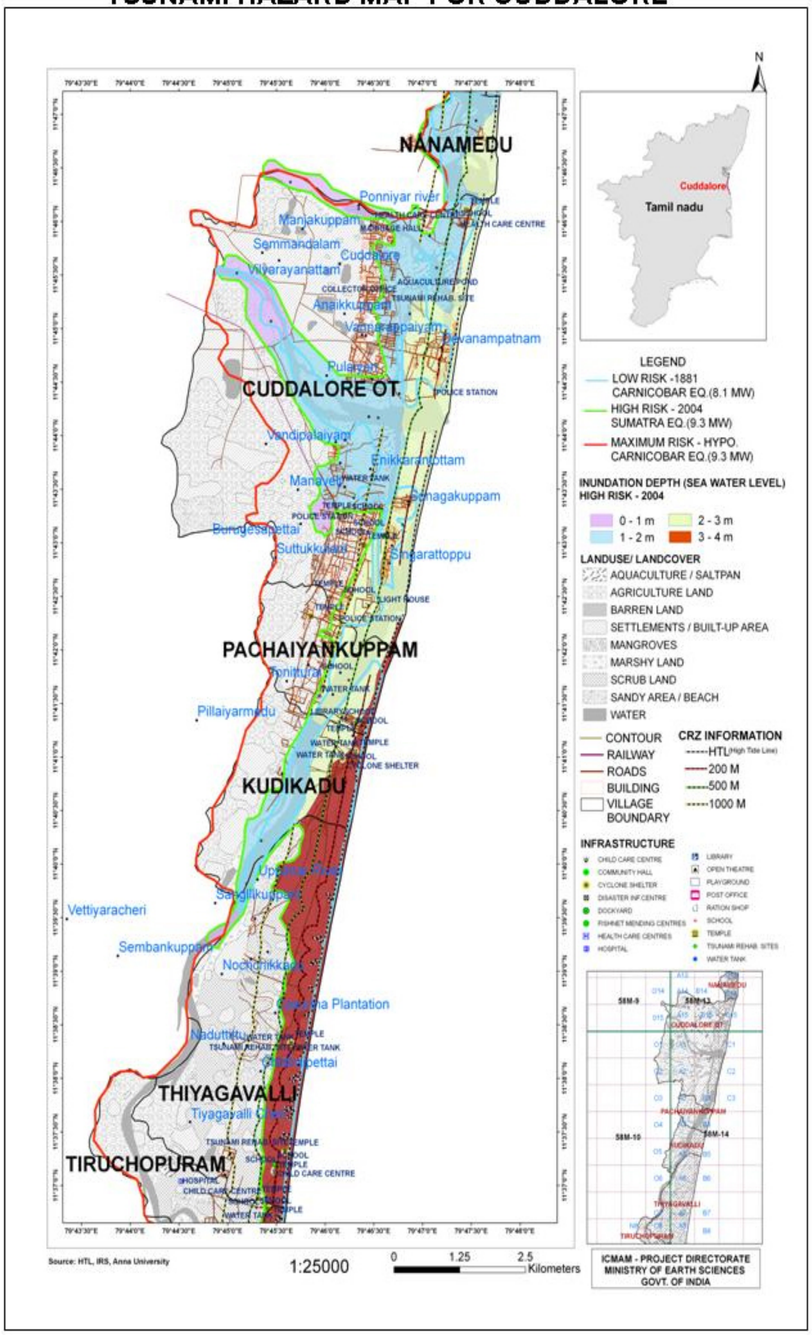
Modeling and Mapping of Tsunami along Indian coast as a part of the early tsunami and storm surge warning system/

TSUNAMI HAZARD MAP FOR CUDDALORE



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Ministry of Earth Sciences
Integrated Coastal and Marine Area Management (ICMAM)
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Govt. of India

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Contents

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1.0 Background

The tsunami of the recent past has put into perspective the need for assessing tsunami hazard in vulnerable coastal areas of India. Following the disastrous tsunami in the Indian Ocean on December 26th 2004, the Ministry of Earth Sciences initiated action towards setting up of the Tsunami Warming System at INCOIS, Hyderabad. As a part of this warning system ICMAM-PD was entrusted with the task of modeling and mapping of vulnerability of coastal areas to tsunami hazard for the entire Indian Coastline.

A project was initiated to study possible risks of an ocean originating inundation due to a tsunami on low-lying, densely populated coastal areas by applying tsunami models constructed using numerical equations. Numerical modeling is an excellent tool for understanding past events and simulating future ones. The use of numerical modeling to determine the potential run-ups and inundation from a local or distant tsunami or storm surges is recognized as useful and important tool, since data from past events is usually insufficient.

Models can be initialized with potential worst case scenarios for the hazard sources or for the waves just offshore to determine corresponding worst case scenarios for run-up and inundation. Models can also be initialized with smaller sources to understand the severity of the hazard for the less extreme but more frequent events. This information is then the basis for creating hazard evacuation maps and procedures. At present, such modeling has only been carried out for a small fraction of the coastal areas at risk. Sufficiently accurate modeling techniques have only been available in recent years, and these models require training to be used correctly. Moreover, detailed bathymetric and topographic data is of utmost importance to run the tsunami models.

Since the source parameters that triggered the December 2004 tsunami are well known, numerical models are first set to capture the past event. Since accurate measurements on inundation and run-up are available for coastal Tamil Nadu the model results are validated using field observations collected immediately after the tsunami.

Bathymetry and elevation data are the principal datasets required for the model to capture the generation, propagation and inundation of the tsunami wave from the source to the land. The TUNAMI-N2 model was used to simulate the inundation due to the December 26th 2004 Sumatra earthquake which had a magnitude of (Mw) 9.1, a fault rupture length of 1200-1300 km and a rupture width of 150 km. Depending upon availability, elevation datasets were derived from Airborne Laser Terrain Mapper (ALTM), Cartosat, RTK while bathymetry datasets were derived from C-Map for near shore areas and from GEBCO for off shore areas.

The model results obtained using the highly resolved bathymetry and elevation data are validated and calibrated using field observations. Since runups are not used in the source calibration, the results obtained provide a uniquely accurate synoptic prediction of tsunami impacts in the coastal areas while capturing the high degree of along coast variation. The model once validated can be used for creating different scenarios of inundation and run-up by varying the source parameters that actually the trigger the tsunami.

On the basis of the model prediction, inundation and water level maps are prepared in different scales for coastal areas of the country. Finally, the tsunami vulnerability maps are generated by adding other datasets such as population, landuse, proximity to coast and tsunami water level outputs generated by the model. These tsunami vulnerability maps would be very useful in disaster management and mitigation activities.

2.0 Tsunamigenic sources threatening India

Tsunamigenic zones that threaten the Indian Coast have been identified, and they are the fault region off Sumatra, North Andaman, Car Nicobar in the Bay of Bengal and the Makran fault in the Arabian sea (Fig.1). Though tsunamis in the Indian ocean are not as common as in the Pacific, India has not been immune to tsunamis. Past records show that parts of the Indian coastline has been inundated due to tsunamis originating in the Indian ocean. Documented evidence report the following occurrence .

- 1868 , 1881 & 1941 Earthquake (M 7.5 & 7.9) generated moderate tsunamis in A & N islands
- 1881 tsunami waves traced in Nagapattinam
- 1945 Makran coast (now in Pakistan) generated giant tsunami in Arabian sea and waves traced in Mumbai

However, except for the occurrence of these disastrous events there are no detailed documentation either on the impact or magnitude of the disaster itself.

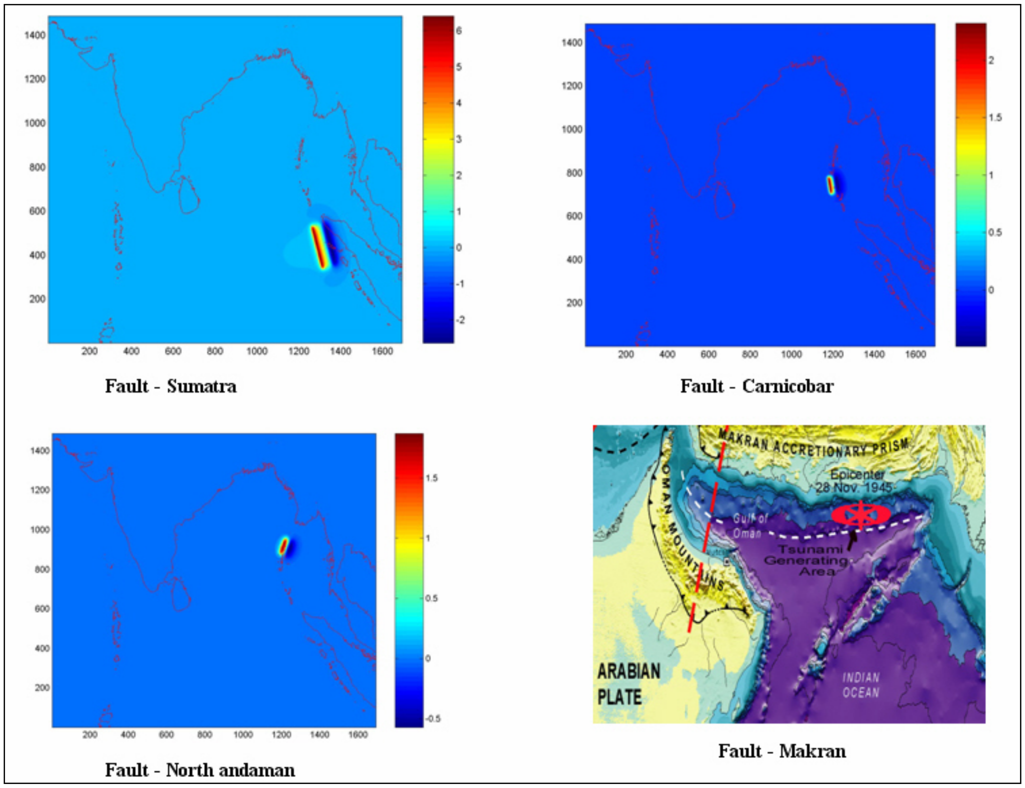

Fig 1. Tsunamigenic Zones which threaten the Indian coast

3.0 Modeling of Tsunamigenic sources

The overall scope of the modeling can be divided into three stages: i) generation, ii) propagation and iii) run-up (inundation). The parameters and type of model employed at three stages are different and depends on the condition of the site and type of hazard. From literature, past earthquake sources and their source parameters were compiled and the possible tsunamigenic sources that pose threat to the Indian coast were identified (Fig.2).

Due to paucity of time, data and resources, a few locations were selected in each of the coastal states and were taken up for study in the first phase (Fig.2). However, the entire coastline will be covered in subsequent phases depending upon acquisition of high resolution elevation and bathymetry data.

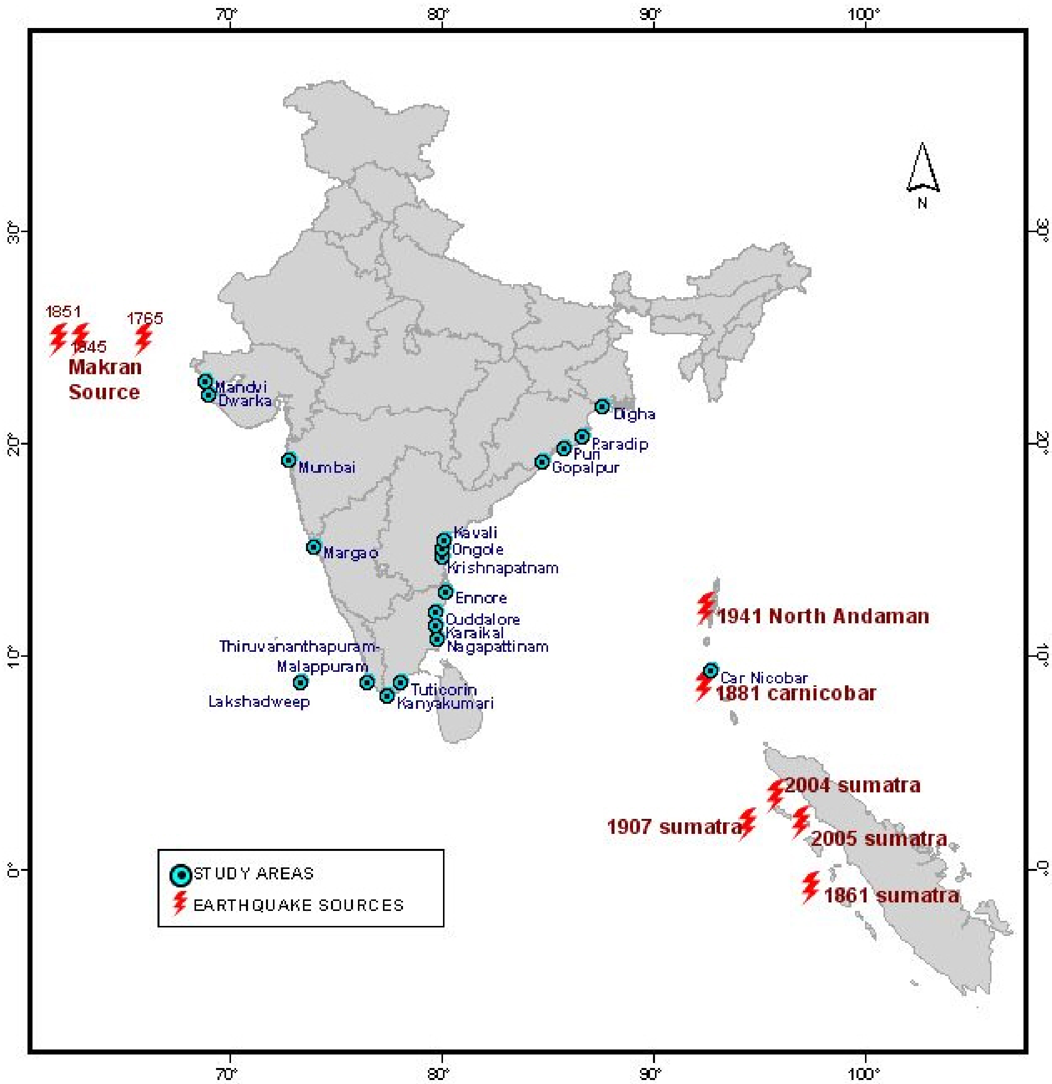

Fig.3. Tsunamigenic sources and study areas for coastal vulnerability

4.0 Numerical models for the prediction on run-up and inundation

The use of numerical modeling to determine the potential run-ups and inundation from a local or distant tsunami is recognized as useful and important tool, since data from past tsunamis is usually insufficient to plan future disaster mitigation and management plans. Models can be initialized with potential worst case scenarios for the tsunami sources or for the waves just offshore to determine corresponding worst case scenarios for run-up and inundation. Models can also be initialized with smaller sources to understand the severity of the hazard for the less extreme but more frequent events. This information is then the basis for creating tsunami evacuation maps and procedures. Such modeling is proposed to be carried out for a entire Indian coast to identify the areas at risk. Sufficiently accurate modeling techniques have only been available in recent years, and these models require training to understand and use correctly, as well as input of detailed bathymetric and topographic data in the area being modeled.

Numerical models have been used in recent years to simulate tsunami propagation and interaction with land masses. Most tsunami models are numerical equations dependent but often employ different numerical techniques applied to different segments of the total problem starting from tsunami generation, propagation and runup on coastal areas. For example, several numerical models have been used to simulate the interaction of tsunamis with islands. These models have used finite difference, finite element, and boundary integral methods to solve the linear long wave equations. These models solve these relatively simple equations and provide reasonable simulations of tsunamis for engineering purposes.

The overall scope of the tsunami modeling can be divided into three stages: i) generation, ii) propagation and iii) run-up (inundation). The parameters and type of model employed at three stages is different and depends on the condition of the site.

5.0 Tsunami Inundation Outputs generated for selected location along the Indian coast

Till date tsunami inundation and water level maps have been generated for selected locations in all coastal states in the Indian Coast. ALTM data was available for a parts of coastal Tamil Nadu, Andra Pradesh, Kerala and Car Nicobar. Ih In the absence of ALTM data, RTK GPS was used to collect elevation data in states such as Gujarat, Maharastra, Goa, Kerala, Orissa and West Bengal.

Some of the tsunami inundation outputs generated for selected locations are given below (Fig.3-12).

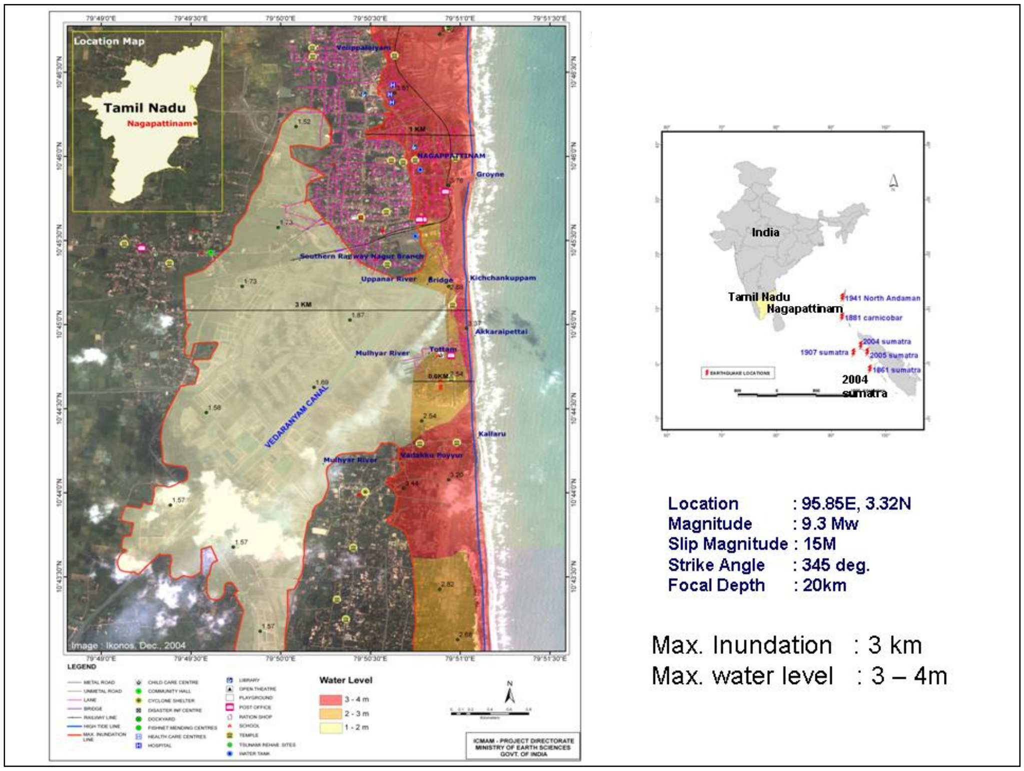

Fig. 3. Inundation in Nagapattinam, Tamil Nadu due to 2004 Sumatra Earthquake source

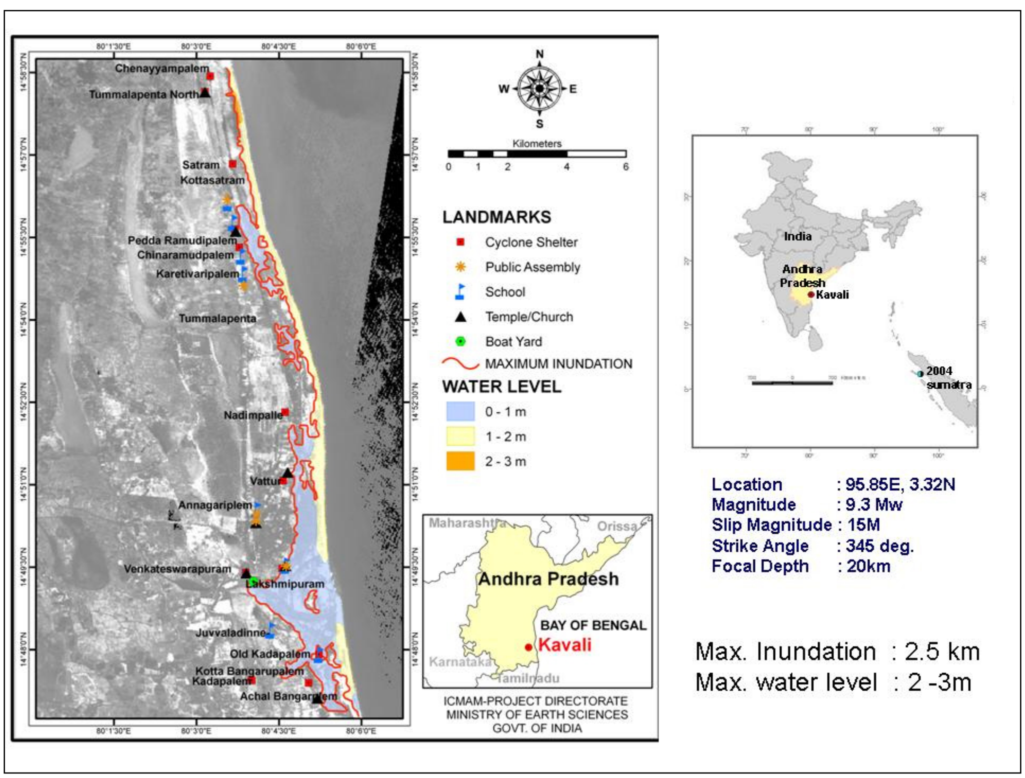

Fig.4. Inundation in Kavali, Andra Pradesh due to 2004 Sumatra Earthquake source

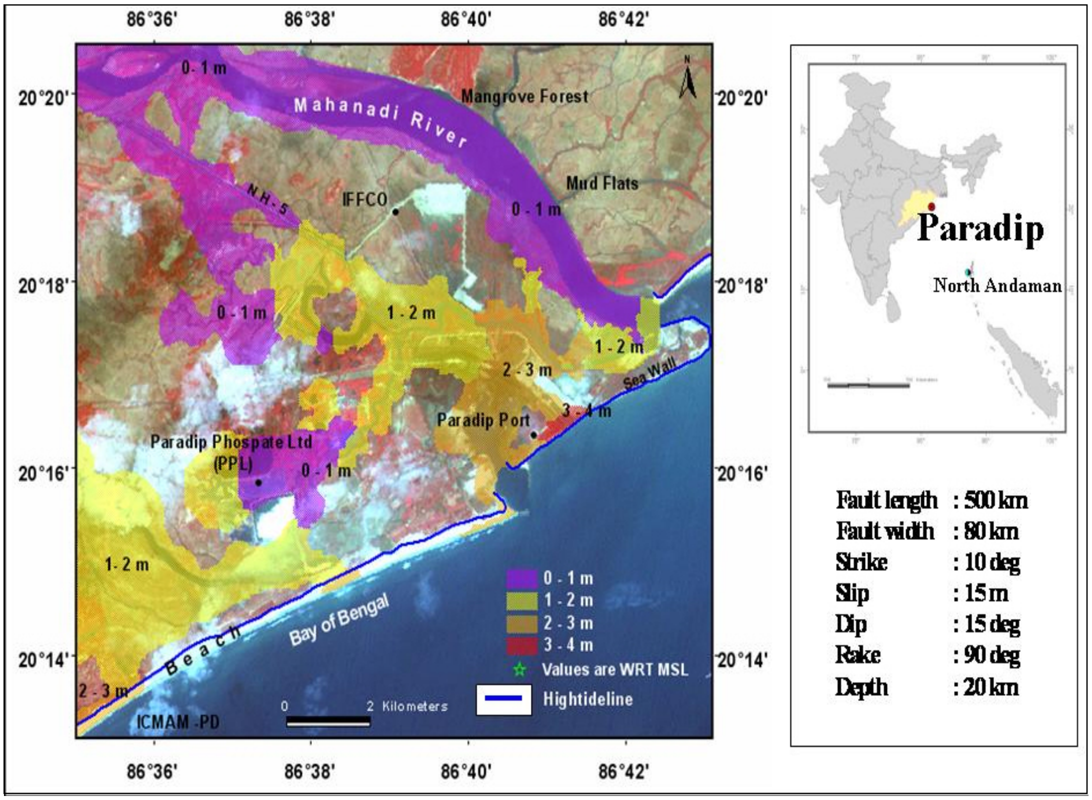

Fig.5. Inundation in Paradip, Orissa
due to hypothetical worst case scenario

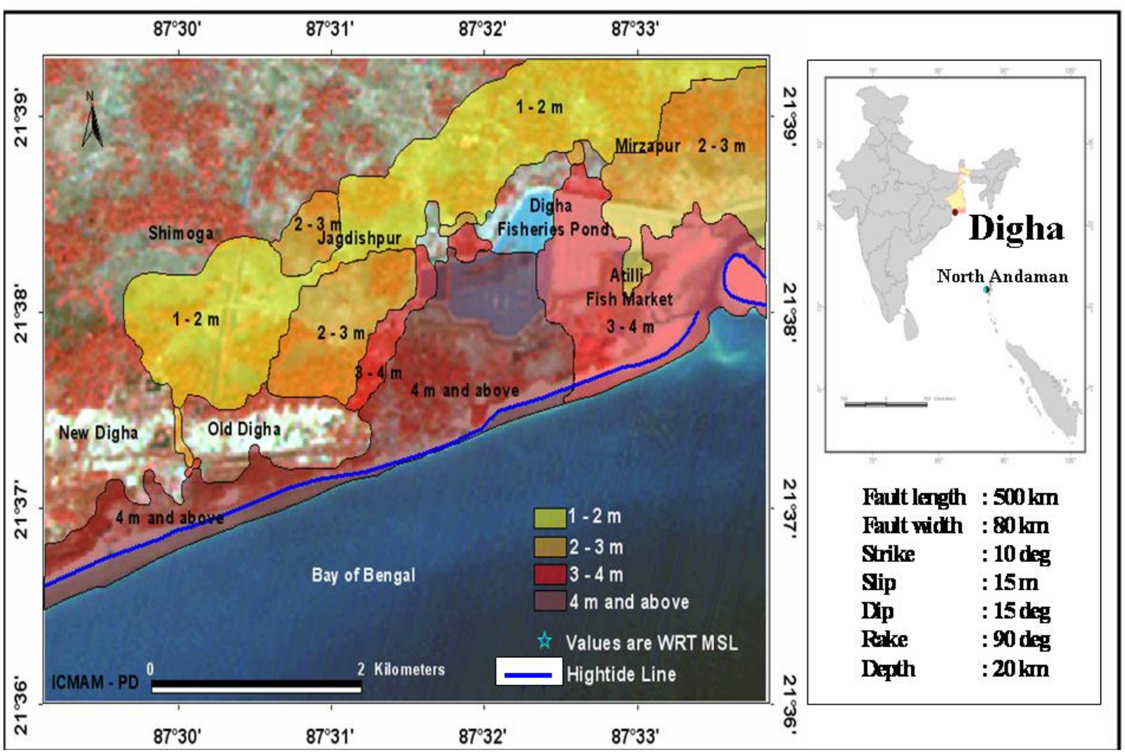

Fig.6 Inundation in Digha, West Bengal
due to hypothetical worst case scenario

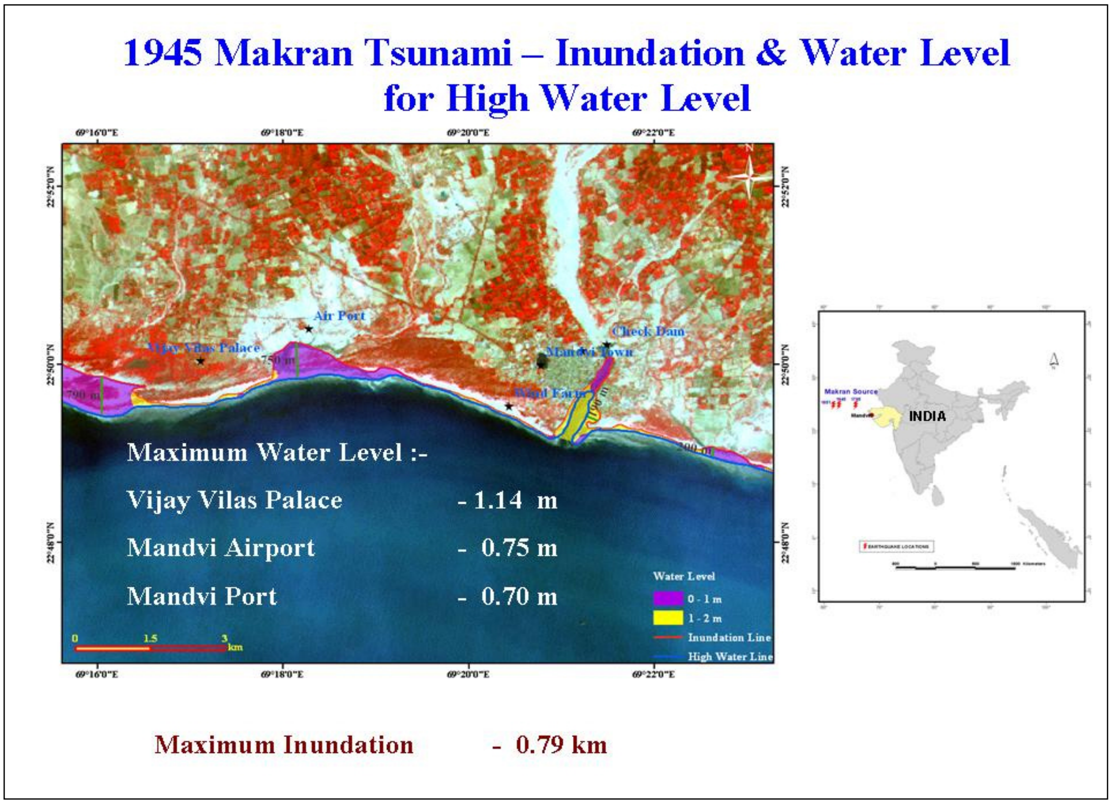

Fig. 7. Inundation in Mandvi, Gujarat,
due to 1945 Makran Earthquake source

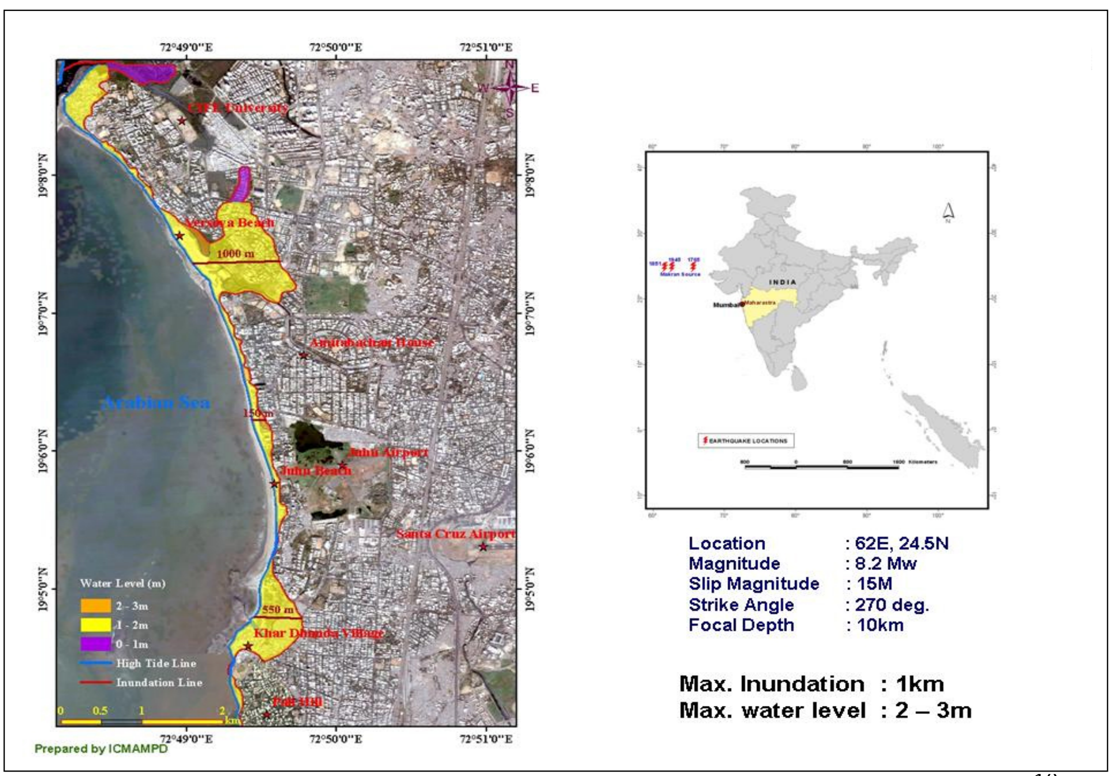

Fig.8. Inundation in Versova, Maharastra
due to 1851 Makran Earthquake source

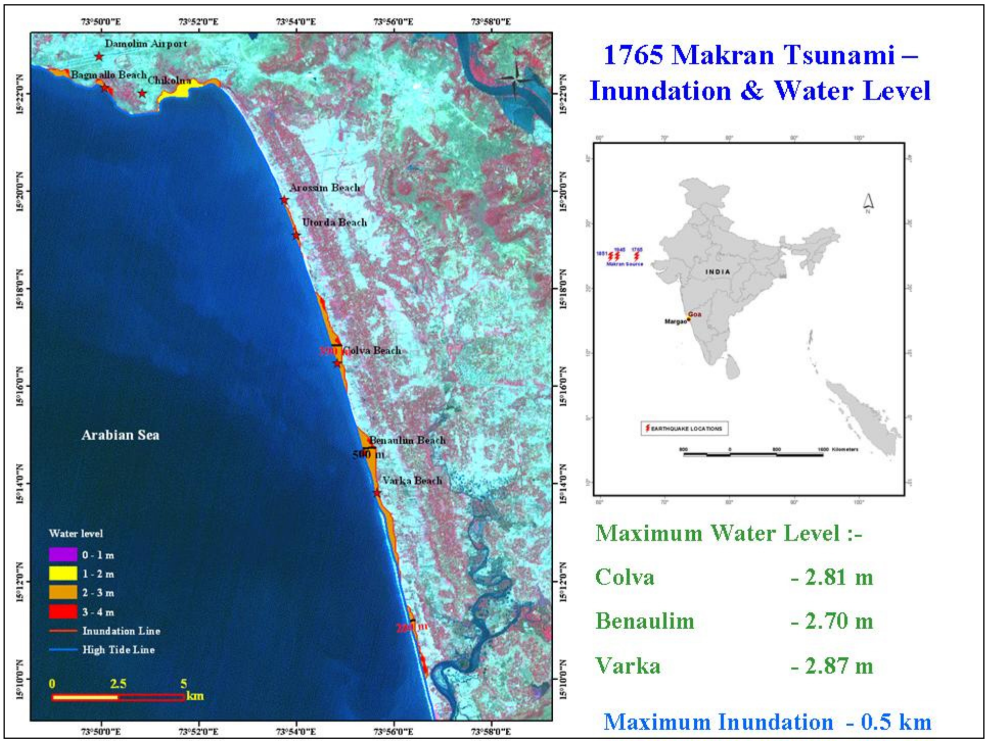

Fig. 9. Inundation in Southern Goa
due to 1765 Makran Earthquake source

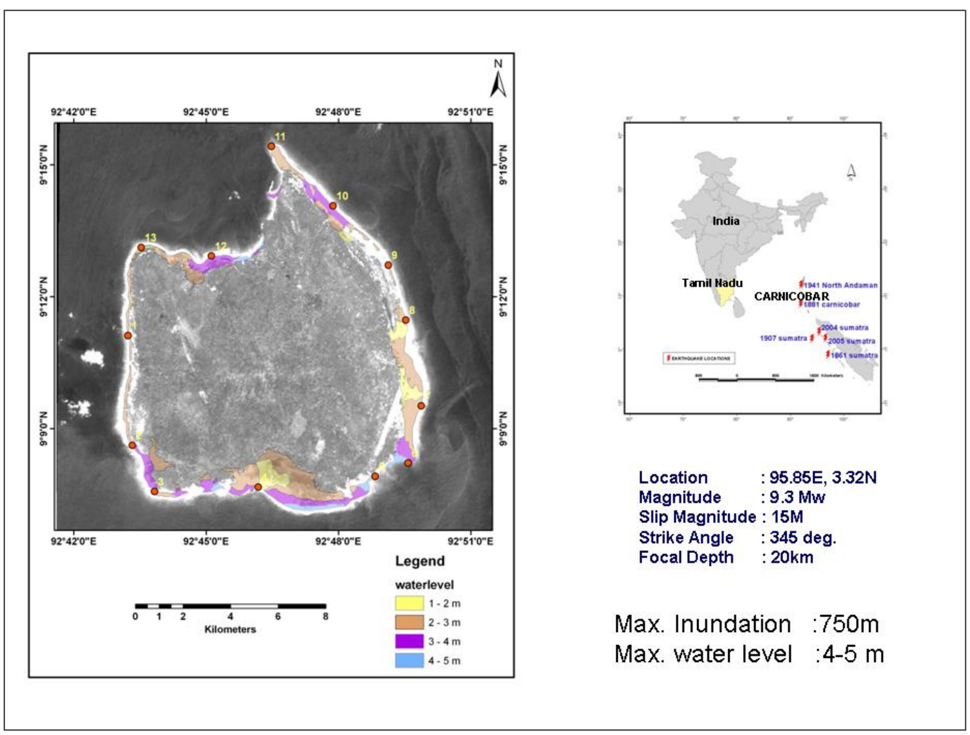

Fig. 10. Inundation in Southern Goa
due to 1765 Makran Earthquake source

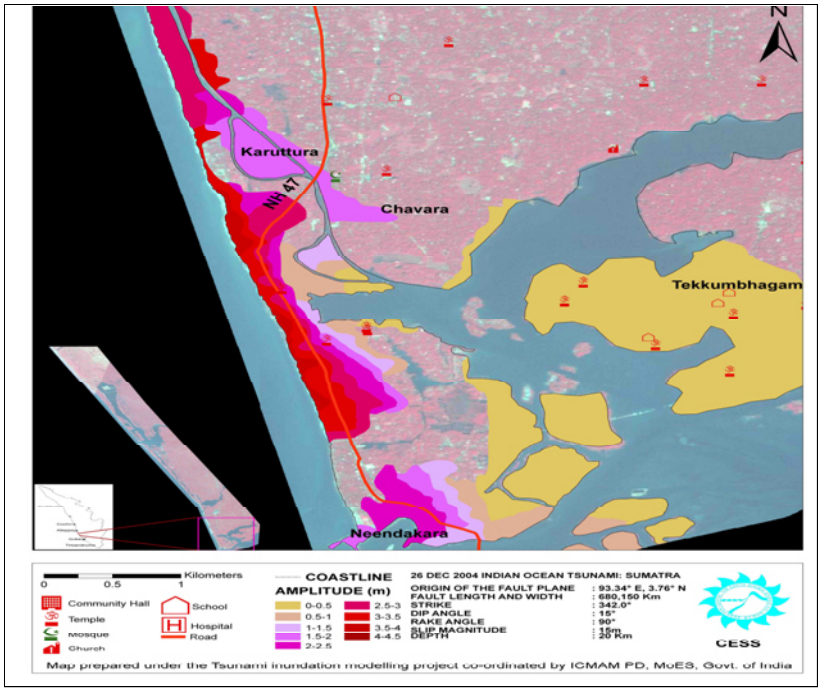

Fig. 11. Inundation in Neendakara-Thottapally sector, Kerala due to 2004 Sumatra Earthquake source

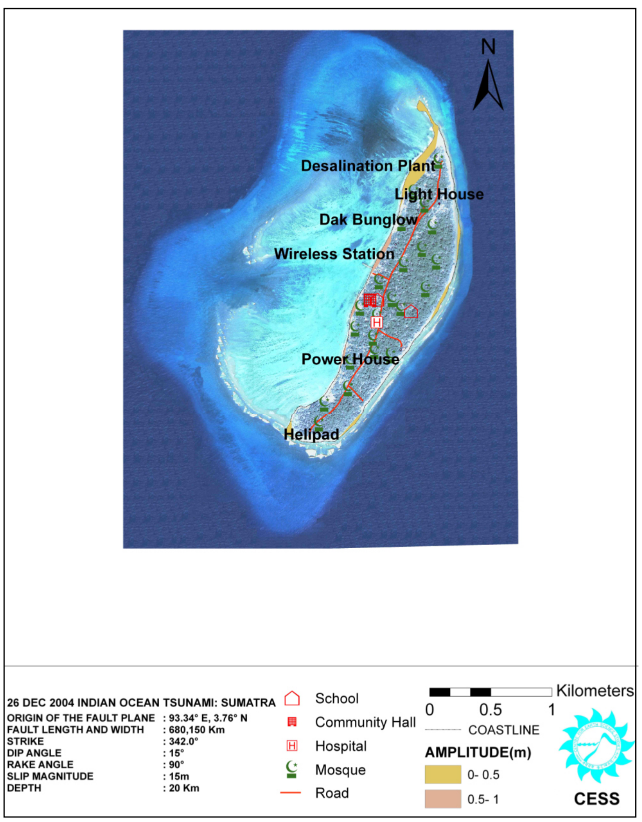

Fig. 12. Inundation in Chetlat island, Lakshadweep, due to 2004 Sumatra Earthquake source

6.0 Preparation of tsunami hazard maps

Tsunami hazard maps have been prepared by incorporating the results of the numerical model on the extent of inundation and run-up, on a base map showing the administrative boundary of the coastal villages. The hazard maps essential show the extent of vulnerability of the coastal zones along with details on landuse, elevation, cadastral land parcels, infrastructure, High tide line, Coastal regulation buffer zones etc (Fig.13).

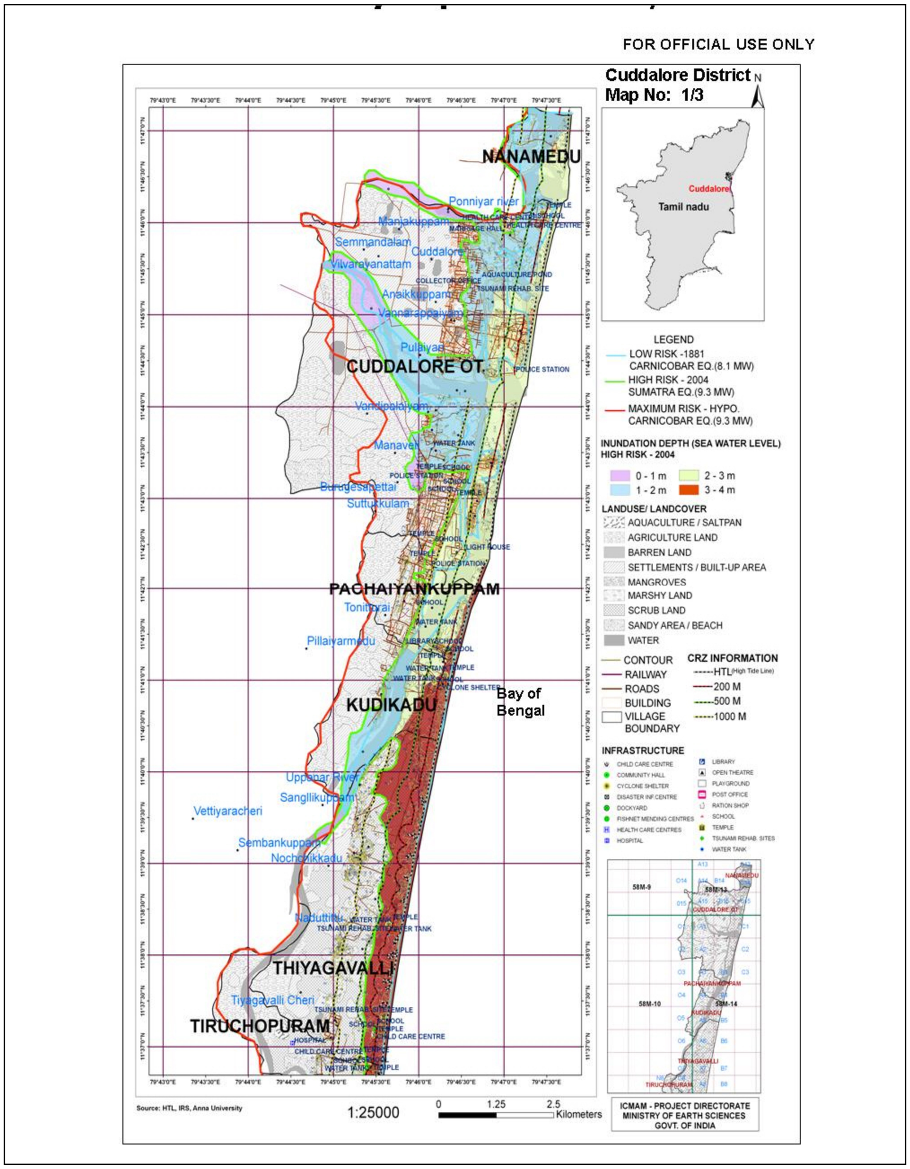

Fig. 13 Tsunami Inundation map for Cuddalore

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