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# Possible Inundation Map of Coastal Areas of Gujarat with a Tsunamigenic Earthquake

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**Abstract:** The western Indian peninsula experienced the most destructive tsunami ever recorded in the Arabian Sea by the 28th November 1945 earthquake (Mw 8.1) in Makran region. The run-up height during the tsunami was of 17m at Makran coast and 11 to 11.5m in Gulf of Kachchh region. Seismic gap area along the subduction zone of Makran is possible site of future great earthquake, which could generate tsunamigenic condition along western Indian coast. Determination of run-up elevation is important aspect to study the inundation in any region, which get affected by off-shore and on-shore geomorphological conditions i.e. bathymetry and near-shore topography. Inundation maps are prepared using Shuttle Radar Topographic Mission (SRTM) data and ETOPOv2v to show the possible areas of inundation due to different wave heights along coastal parts of Gujarat state. Results shows that more than 2 m run-up elevation is showing possibility of inundation in Jakhau and Kandla areas of Gulf of Kachchh region whereas, the Saurashtra region shows less possibility of inundation. As the state has important installations like ports, jetties, industries along the coast and also other socio-economical perspective which can be affected by such an event, hence the demarcation of possible inundation areas is important for determination of future tsunami hazard demanding more detailed work.

**Keywords:** Bathymetry, Gujarat coast, geomorphology, inundation, tsunami

## Introduction

Ports and jetties are important engineering structures along the coast to provide a cost-effective system for transporting huge quantities of goods and raw materials in and out of a country. Along the coastal part of Gujarat there are more than nineteen active ports, three refineries, and a number of jetties, several oil storage installations and chemical industries (Gujarat Maritime Board website) boosting economy of the region. In the Gulf of Kachchh region alone there are eleven major and minor ports (Fig. 1). Approximately twenty jetties which supports the fishing business and several industries like 21 salt work units in inter-tidal region, wind farms, are part of coastal zones in Gujarat. Among all the ports of Gulf of Kachchh region e.g. Jakhau, Mandvi and Mundra; Kandla is the only free-trade port and also one of the significant large ports in India having enormous financial investments. Apart from this, Gulf of Kachchh also has several ecologically sensitive flora and fauna and tourism- related businesses. The tsunamigenic condition can affect these natural, anthropogenic features and directly or indirectly affect the economy of the region. It is worth mentioning here that the Kandla port was affected by 28th November 1945 tsunami, generated due to magnitude M 8.0 earthquake (Quittmeyer, 1979; Rastogi, 2005) having epicentre at 25.204° N: 63.420° E (Fig. 2) in Arabian Sea at a distance of ~100 km south of Karachi and 87 km SSW of Churi in Baluchistan (George, 2006). The height of tsunami waves was of 11.0 m to 11.5 m in the Gulf of Kachchh region (Pendse, 1948; Rastogi, 2006). At that time Kandla was not a developed port disparate today and was almost a barren place. If a tsunami of similar dimensions occurs in future, then the losses in terms of economy and life would be unbearable as huge financial investments have been made in Kandla region.

The seismic activities in and around the Makran coast (1909-2007) have been studied (Fig. 2) which indicate seismic gap in western part of Makran coast region (Rastogi, 2006) (Fig. 2). Therefore, possibility of destructive tsunamis in the northern Arabian Sea cannot be overlooked from this region. Although the geological and historical accounts for tsunami in Gulf of Kachchh region are not well documented, some references suggest the reach of the waves generated by this affected part of western Indian coastal regions up to Mumbai and possibly elsewhere.

The increase in intensity of economic expansion of coastal part and the changed scenario of socio-economic conditions demands detailed studies of the coastal areas which can be

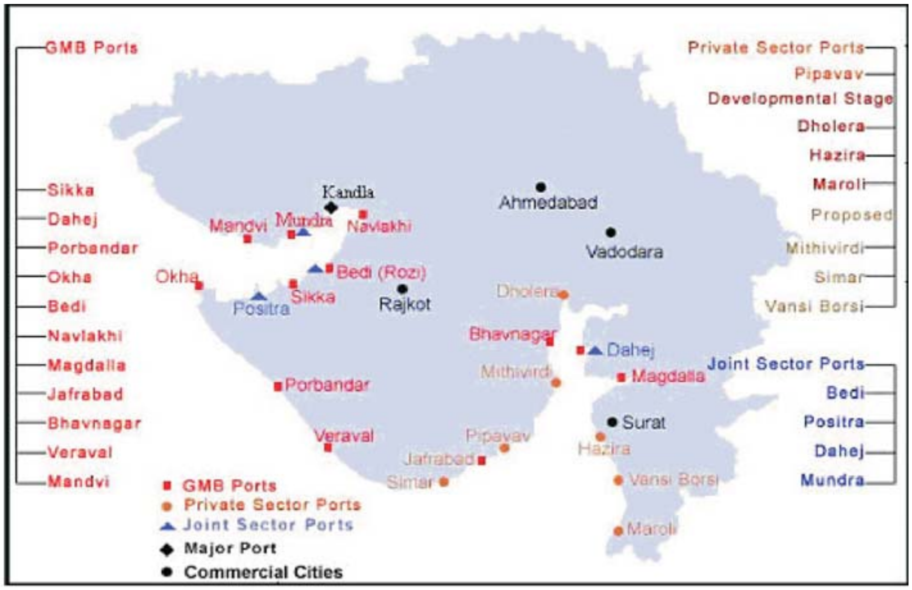


**Fig. 1.** Location of ports and jetties along Gujarat coast.

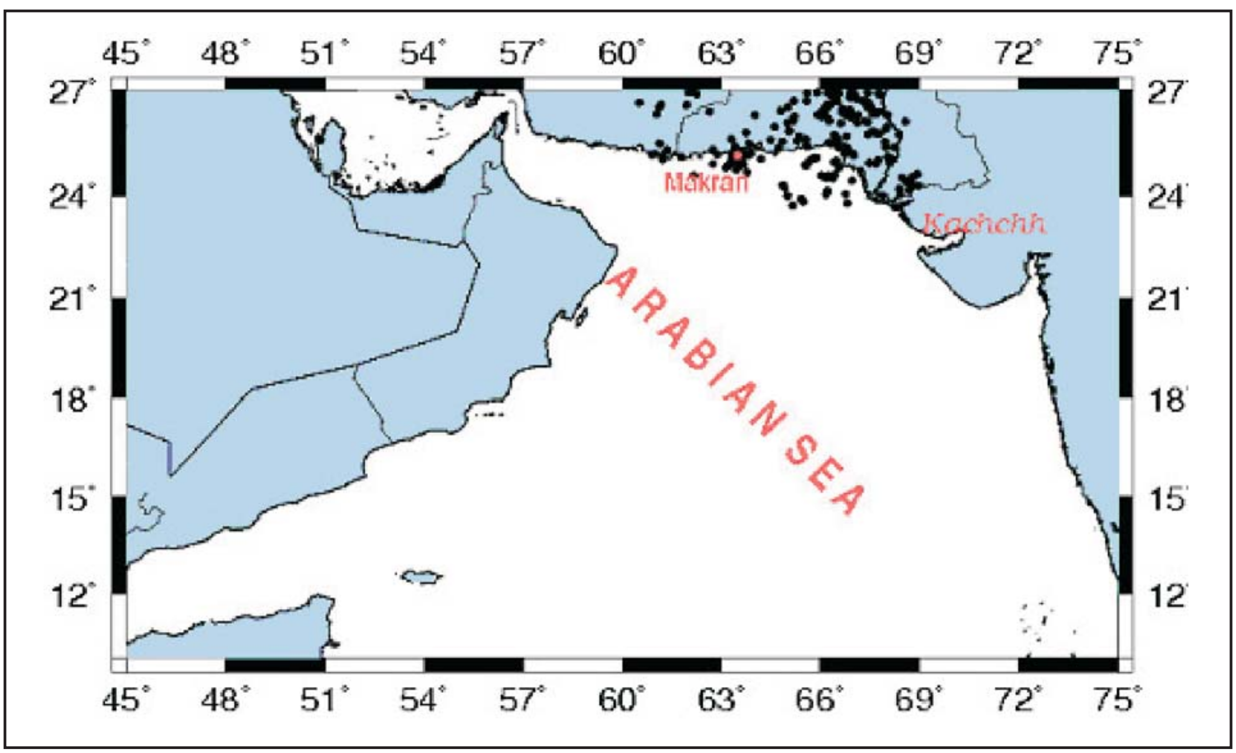


**Fig. 2.** Map of the Makran coast and seismic activities in and around the coast (Quittmeyer, 1979).

affected from the devastating effects of tsunami waves generated from submarine seismic activity. In light of this, an attempt is made to prepare a vulnerability map for Gulf of Kachchh region showing coastal region susceptible to inundation due to different wave-heights.

## Regional Tsunamigenic Sources around West Coast

The west coast of India could be hit by tsunami with occurrences of tsunamigenic earthquakes from the different sources e.g. Makran coast, Persian Gulf area, Aden Gulf area, Socotra island region, Diego Garcia region and Saurashtra-Kachchh region (Bapat, 2007) are possible sources for tsunamigenic earthquake, which could affect the coastal regions of Gujarat state. In the subduction zone of the Makran coast at Baluchistan, Arabian plate sinks under the Eurasian plate. The sesimotectonics of the Makran subduction zone and earthquakes record of the region, including recent earthquake of October 8, 2005 in Pakistan are indicative of the tectonic activity along the entire southern and southeastern boundary of the Eurasian plate. The tectonic stresses at the margin of this plate and other micro-plates could be possible sources for triggering tsunamigenic earthquakes in the northern Arabian Sea and subsequently affecting the coastal areas of western India.

Historical seismic records indicate occurrences of earthquakes up to M 8.0 in these regions (Fig. 2). The earthquake records from the source region indicate that most of the above sources were seismically less active for about last thirty years. However, since November 2005 onwards the activity is seen in the above- mentioned source region. Events were monitored from tsunami point of view. It was observed from the records based on the tide gauges data in some ports on Gujarat coast that the heights of wave co-incident with these events were in the range 55 to 65 cms (Bapat, 2007). The elevation datasets are the most important input for inundation mapping in tsunami-prone areas. Preparation of a vulnerability map could inform coastal community and others about the susceptibility of a particular area to inundation corresponding to various wave-heights. The State has important installations like ports, jetties, industries along the coast and also other socio-economical perspective which can be affected by such an event and hence the determination of possible inundation areas is important.

## Data and Methodology

For preparation of the inundation map of the study area two dataset were used to study the topography and bathymetry of the coastal region. The data was extracted from SRTM and ETOPOv2v respectively (Fig. 3). Moreover, the geomorphic set-up of the coastal zone was taken in consideration to study inundation pattern of vulnerable geomorphic units. Bathymetric map (Fig. 3) shows details of the ocean bottom features like continental shelf to abyssal plain, valley, ridges, etc. of the study area. Bathymetry of continental shelf area plays an important role in inundation of coastal regions from tsunami as the accommodation space of it is very crucial in amplifying the tsunamigenic waves. It means the near-shore shallow nature of off-shore region increases the chances of inundation by the tsunami increases in the coastal areas. Here we describe the bathymetry, geomorphology of the Gulf of Kachchh region and possible inundation in the areas of it with different run-up elevations. The data was viewed and processed with ArcView GIS software.

## Results and Discussions

Figures 4 a & b depict the bathymetry set-up of the Makran coast and western Indian continental margin derived from ETOPOv2v data from the USGS. Figures 3 (a & b) show the average profile along the western continental shelf areas. Accordingly, the continental shelf area is narrow in the off-

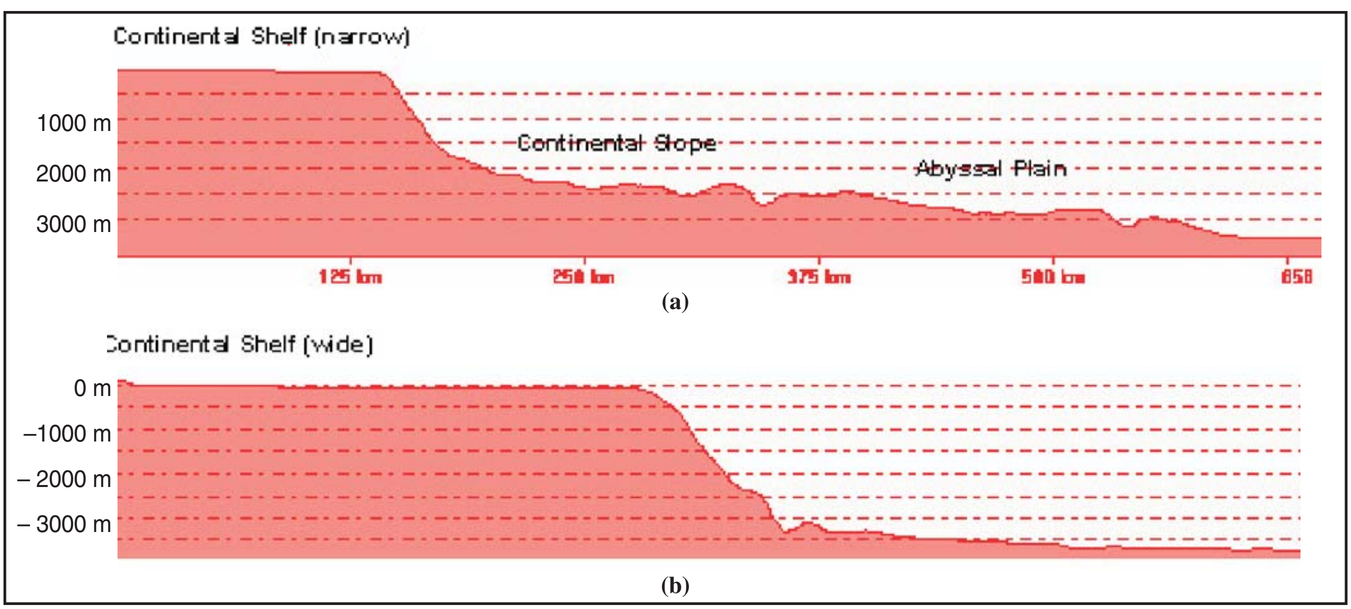


**Fig. 3.** Average cross-profile of the western coast of India. (a) Accordingly the continental shelf area is narrow in the offshore of Kachchh region. (b) It is wider in the south Gujarat and Maharashtra offshore region.

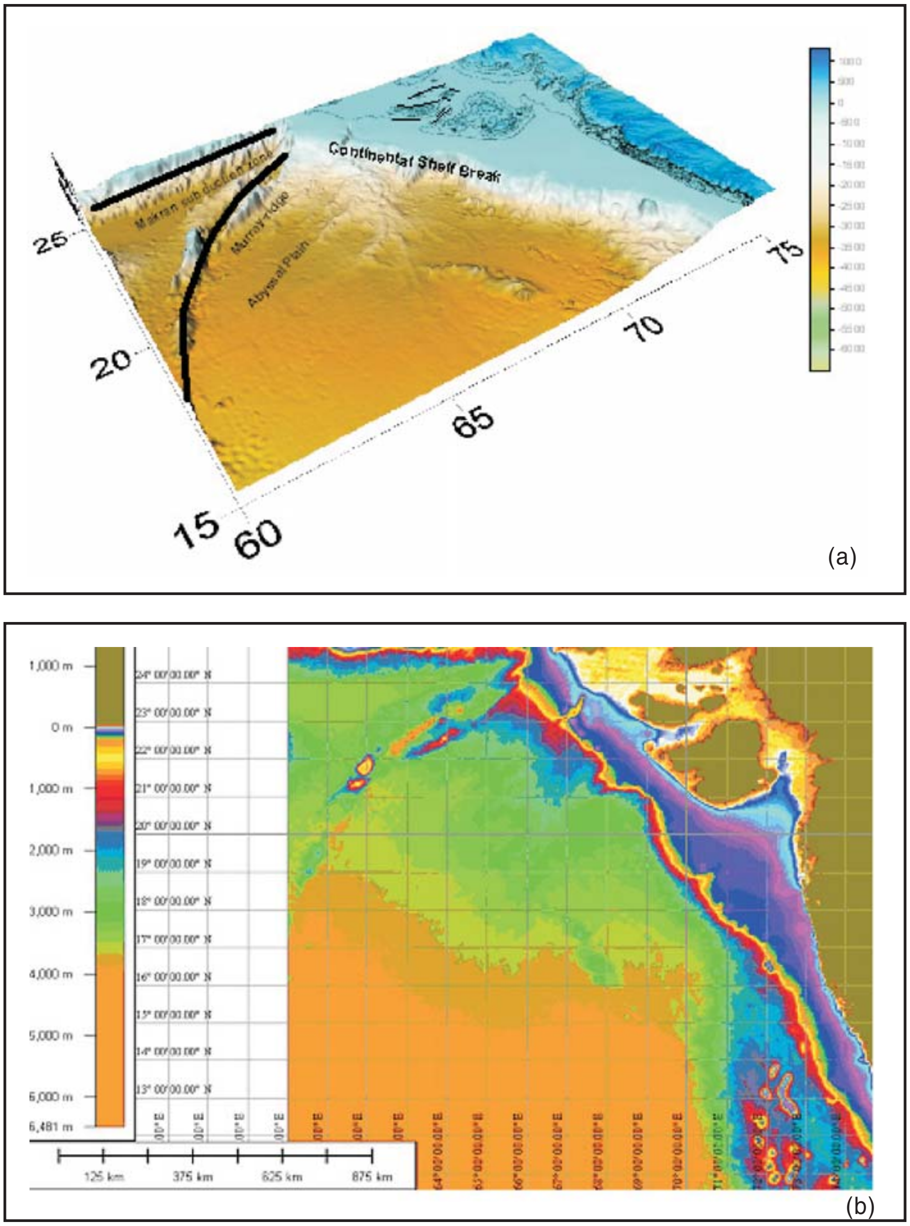


**Fig. 4.** Bathymetry of the off-shore region of western Indian continental margin (a) Perspective and (b) Plan view

shore of Kachchh region (Fig. 3a) whereas it is wider in the south Gujarat and Maharashtra off-shore region (Fig. 3b). Tsunami wave propagation depends mainly on bathymetry. In order to accurately evaluate the tsunami propagation and the tsunami arrival times at different locations, precise bathymetry is required (Satake, 1988). Figures 3 a & b show the average cross profile of the western Indian continental shelf. Accordingly, the continental shelf area is narrow in the off-shore of Kachchh region (Fig. 3a) where as it is wider in the south Gujarat and Maharashtra off-shore region (~160km and ~320km respectively) (Fig. 3b). Therefore, tsunami wave propagation resulting in the inundation will be different at these two regions. The continental shelf break in the region occurs at about –300 m in the Arabian Sea region of Gujarat. The continental shelf break represents the structural control on it after the breakage of Indian plate from the Gondwanaland. The control of the bathymetry over the run-up elevation for December, 2004 tsunami has been worked out for Kerala and eastern part of south India (Kurian et al., 2006).

Here we present three different regions from coastal part of Gujarat (Gulf of Kachchh, Saurashtra and south Gujarat) to show the possible inundation with respect to the off-shore bathymetry and coastal geomorphic setup. The chances of inundation are more in the region where the near-shore topography is low. Difference in the geomorphic setup can result into varied inundation scenario of tsunami effects. For example the linear beaches with low topographic elevation are more susceptible to inundation where as the beach ridges having high topography protect the area from inundation.

Gulf of Kachchh is the nearest region prone to be affected by the tsunami generated in the above mentioned source regions. North-Western part of the Kachchh coastline would be the first region to get affected by tsunami from this region. Here the near-shore topography is very low (1-5 m msl) and is covered with vast intertidal areas. The near-shore bathymetry is steep up to (–5 m) so the waves could be amplified here. Thus, these regions are more prone to flooding due to tsunami. It is worth mentioning here that normal spring tides occasionally flood the region. Thus, there are all possibilities of flooding in the region. Jakhau port is located to northern part of Gulf of Kachchh which is economically important location lying within the reach of the 5 m inundation case. The possible area of inundation due 5 m run up height in this part is approximately 623 sq.km. Apart from this, the coastline is ecologically also important as it is covered with the wetland

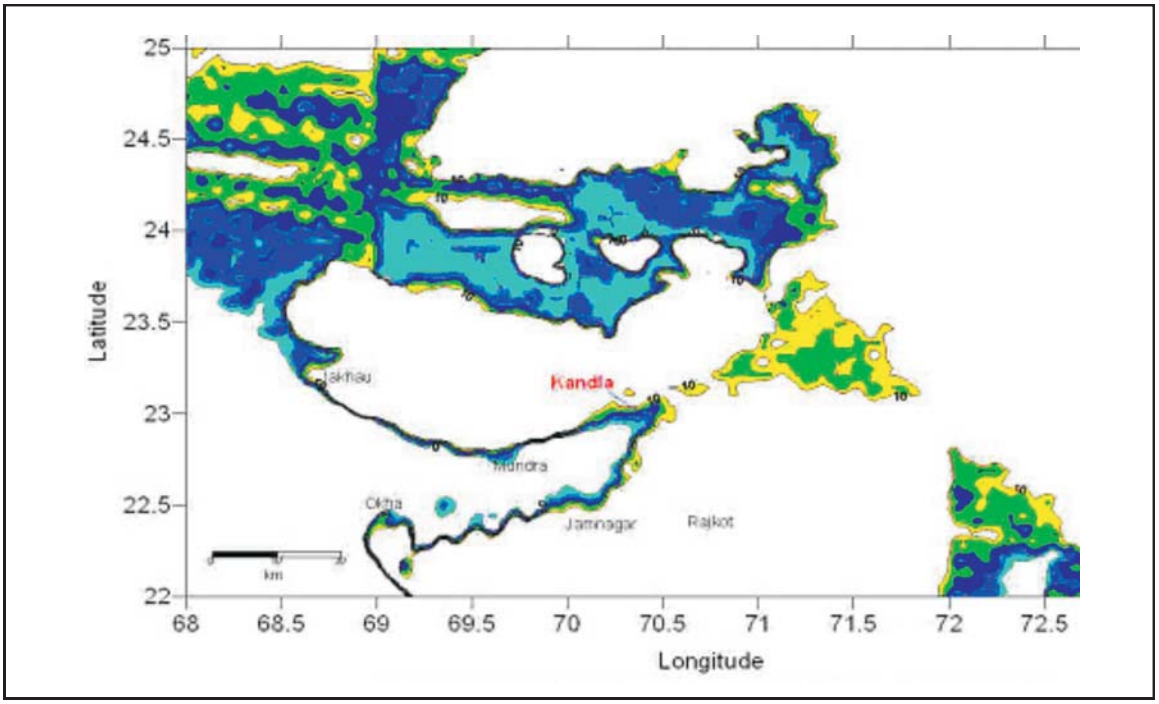


**Fig. 5.** Possible inundation areas in Gulf of Kachchh region due to different run-up elevations.

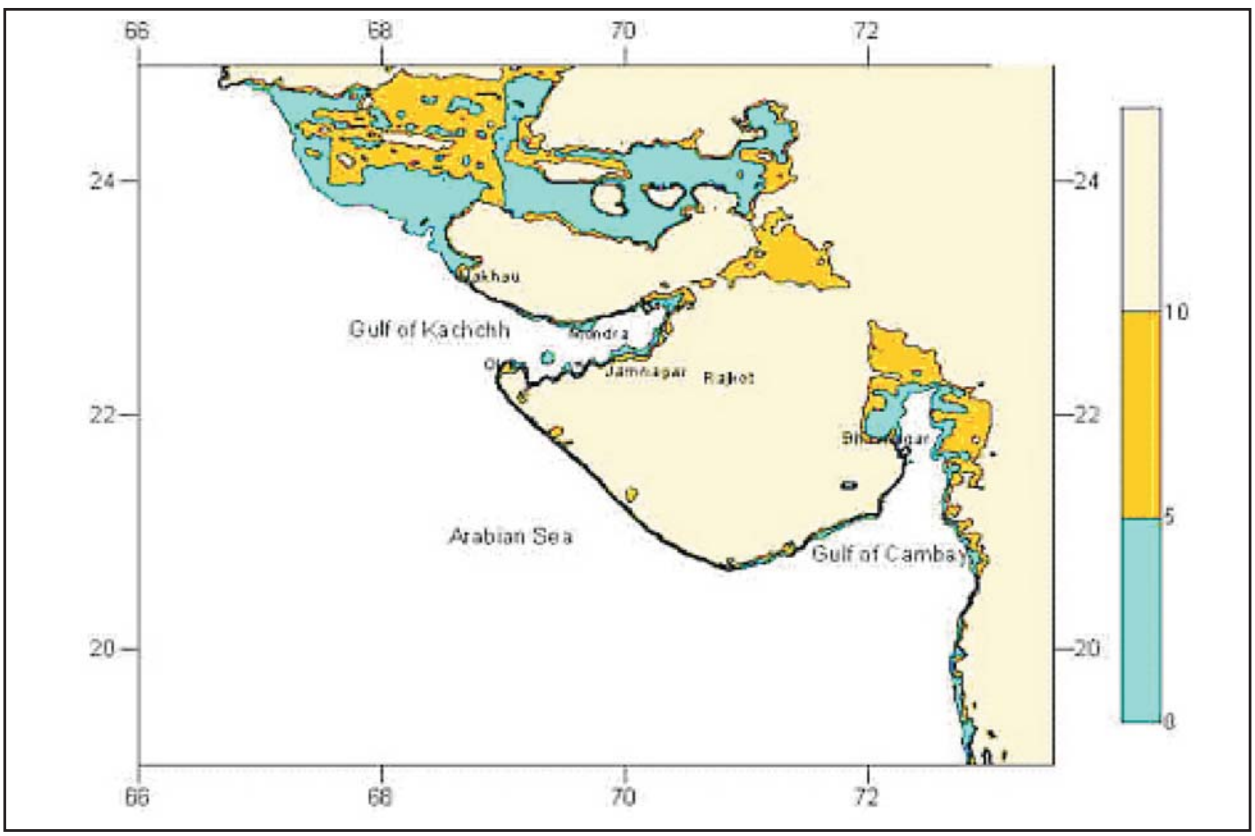


**Figure. 6.** Inundation scenario due to 5 and 10 m in Gujarat. Note that Gulf of Kachchh and Gulf of Cambay region are having low lying areas, whereas Saurashtra is having high areas so less chances of inundation except few regions.

vegetation which protects the coastal erosion, this can also be affected by the high run-up conditions. There are reports of these regions affected by cyclone of 1999. Mandvi coast which is in the middle part of Gulf of Kachchh is covered with the coastal dunes and linear beaches. The average height of the dunes is 5 m-10 m which protects the backshore areas from inundation. However, these dunes are composed of detrital, coarse-grained sand which can be easily eroded with the wave splashes by the tsunamigenic conditions. Figure 5 show the inundation map for Gulf of Kachchh region. Map shows that the NW region of Gulf of Kachchh including Jakhau port area and inner most part of the Gulf of Kachchh i.e. Kandla/Navlakhi region is more susceptible to inundation. In both of the cases the >2 m run-up height can inundate large areas. In comparison to Gulf of Kachchh coastline the Saurashtra coastline which is protected with high cliffs (20 m) made up of Miliolitic limestones is not showing any inundation except at few places i.e. near Porbandar in SW Saurashtra (Fig. 6).

Kandla is located in the Gulf of Kachchh region; here the elevation is about 3.8 m above msl and geomorphologically the tidal flats cover the region with numerous creeks. Compared to other regions of gulf area, the elevation of Kandla port area is low and is susceptible to inundation in case of 3 m run-up height. Normal cyclonic conditions and storm surges have also affected this region in the past. Gulf of Kachchh region is ecologically also very important as the Marine National Park is located in it which supports coral reefs, mangroves, etc. and minor rise or fall in the water level can affect these sensitive species. These areas lie in the low elevated intertidal regions of Gulf of Kachchh region.

## Conclusions

The Gujarat coast of India is vulnerable to tsunami attack. The Gulf of Kachchh and Gulf of Khambat could be severely hit and economic losses would be too high. The lessons learnt from the Dec 2004 tsunami could be used for future planning. Ports, jetties, estuarine areas, river deltas and population could be protected with proper methods of mitigation and disaster management. Clubbing the advanced computer modelling, marine parameter measurements by ocean bottom seismometers and satellite, installations of tide gauges and tsunami detection systems and also using conventional and traditional knowledge, it is possible to develop a suitable tsunami disaster management plan.

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