TSUNAMI DETECTION & ASSESSMENT USING REMOTE SENSING AND GIS

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Abstract— Coastal zones are more prone to natural disaster better management strategies and disaster management planning is necessary for the planning of coastal areas. Remote sensing, GIS, Information technology are widely used now a days for better management of coastal areas. GIS and web technology makes it an extremely powerful tool to identify indicators of potential disasters. Information sharing through Internet reduces data acquisition time and thus providing efficient way to carry out real time disaster predictions occur at coastal areas like Tsunami, Cyclones, and Floods. GIS, RS & GPS is useful in disaster management applications & for decision making. Evolution of computer technology and availability of hardware is helpful for rapid expansion of GIS in both disaster research and practice for better management of coastal hazards. GIS is useful for hazard zone mapping and during emergency conditions mitigation of people can easily possible using these maps. As Gujarat has longest coastal area we are focusing on various disasters occur at Gujarat coast and how to reduce impact of disaster by using remote sensing and GIS technologies.
Keywords— Remote Sensing, geographic information system (GIS), earthquake, tsunami, Tsunami Risk, Tsunami warning, Monitoring of Sea level

1. INTRODUCTION

A tsunami is a series of waves with a long wavelength and period (time between crests). Time between crests of the wave can vary from a few minutes to over an hour. Tsunamis are often incorrectly called tidal waves; they have no relation to the daily ocean tides. Tsunami (soo-NAH-mee) is a Japanese word meaning harbor wave. Tsunamis can occur at any time of day or night.
Tsunamis are generated by any large, impulsive displacement of the sea bed level (Fig.1). Earthquakes generate tsunamis by vertical movement of the sea floor. If the sea floor movement is horizontal, a tsunami is not generated. Earthquakes of $M > 6.5$ are critical for tsunami generation. Tsunamis are also triggered by landslides into or under the water surface, and can be generated by volcanic activity and meteorite impacts.

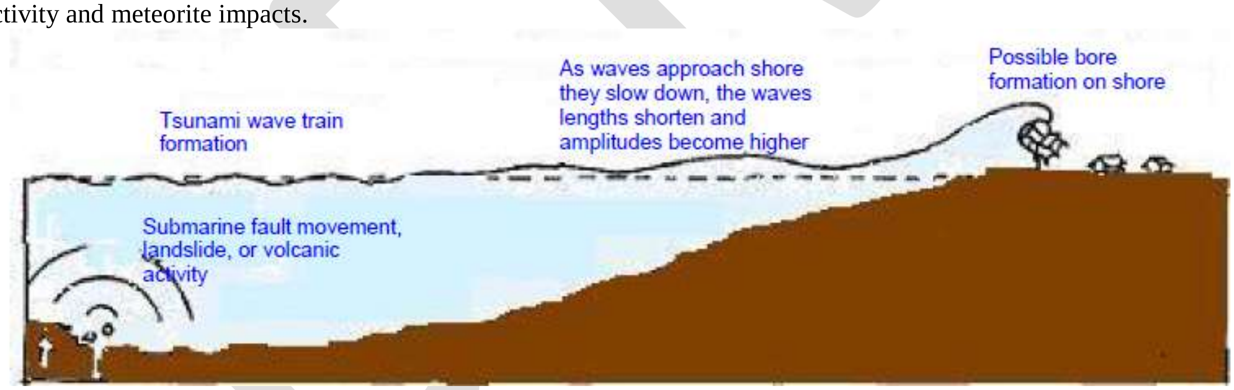

Fig 1- Wave Train of Tsunami. Source: - International Tsunami Information Centre – Geologic Hazard

On the average, there are two tsunamis per year in the Pacific Ocean somewhere, which cause damage near the source. Approximately every 15 years a destructive tsunami occurs in Pacific. The destructive tsunami on Dec 26th, 2004 on the Indian Coast in terms of its impact seems to have occurred for the first time in the history.
Tsunami velocity is dependent on the depth of water through which it travels (Velocity equals the square root of water depth h times the gravitational acceleration g, that is $V = \sqrt{g\,h}$). Tsunamis travel approximately at a velocity of 700 kmph in 4000 m depth of sea water. In 10 m of water depth the velocity drops to about 36 kmph. See Fig.2

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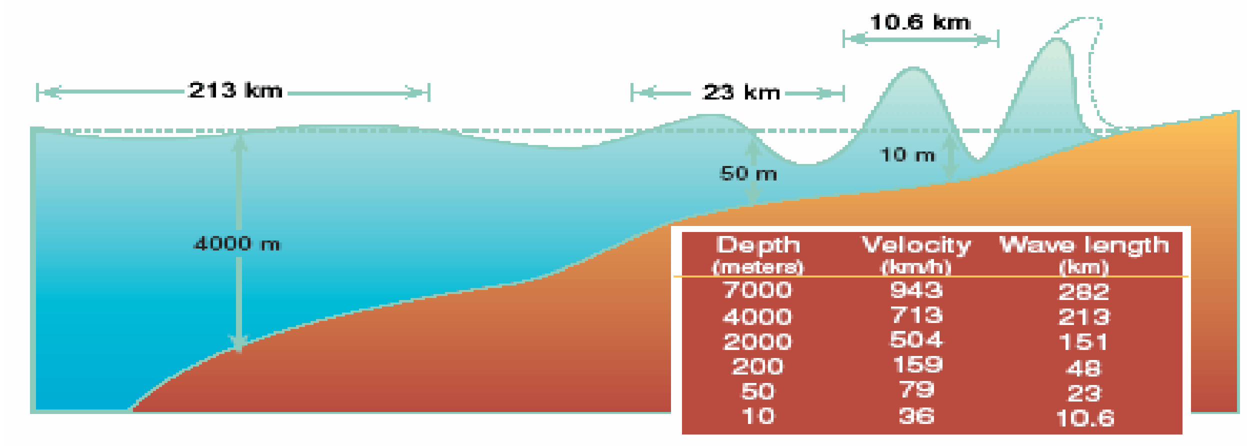

Fig 2-Tsunami Travel Calculation.(Source- http://www.prh.noaa.gov/pr/itic/library/pubs/great_waves/tsunami_great_waves_4.html)

Fig.3 Indian Ocean Tsunami of Dec.26th, 2004

For example, the tsunami from Sumatra coastal earthquake travelled to Tamil Nadu coast in about two Hours. See. Fig.3• Even on shore tsunamis speed is 35 – 40 km/h, hence much faster than a person can run. Tsunamis range in size from centimeters to over 30 m height. Most tsunamis are less than 3 m in height. In deep water (greater than 200 m), tsunamis are rarely over 1m high and will not be noticed by ships due to their long period (time between crests). As tsunamis propagate into shallow water, the wave height can increase by over 10 times. Tsunami heights can vary greatly along a coast. The waves are amplified by certain shoreline and bathymetric (sea floor) features. A large tsunami can flood land up to1.5 km from the coast. The force of some tsunamis is enormous. Large rocks weighing several tons along with boats and other debris can be moved inland hundreds of feet by tsunami wave activity. Homes and other buildings are destroyed. All this material and water move with great force and can kill or injure people. Normally, a tsunami appears as a rapidly advancing or receding tide. It some cases a bore (wall of water) or series of breaking waves may form. Sometimes a tsunami causes the water near the shore to recede by 0.5 – 2.0 km, exposing the ocean floor, and then the wave crest comes with a high speed. Tsunamis can travel up rivers and streams that lead to the sea.

2. Tsunami Risk in India & its Assessment.

The following hazards are seen to occur in the coastal areas of India
1. Earthquakes
2. Cyclonic wind
3. Storm surge in cyclones
4. Flooding by incessant rain
5. Tsunami
Fire is also known to occur quite frequently in many such areas. The situation on the west and east coast of India is given in Table 1 & 2 respectively.

Table 1 Multi Hazard Data for West Coast of India

Name of coastal State	**Vulnerable for Hazard**	**Design Cyclonic Wind (IS:875III) (m/s)**	**Probable Maximum Storm Surge Heights (m)**	**Astronomical High Tide above Mean Sea Level (m)**	**Flood Proneness**	**Tsunami Prone-ness (m)**
Gujarat	Tsunami, Flooding by incessant rain, Storm surge in cyclones	50 & 47	2.5 – 5.0	1.1 –4.1	In 5 coastal districts	10 – 12 (In 1945)
Dadra & Nagar Haveli	Storm surge in cyclones	44	5.0	1.9	---	To be Estimated
Daman & Diu	Storm surge in cyclones	50 & 44	5.0	1.1	---	To be Estimated
Maharashtra	Storm surge in cyclones , Flooding by incessant rain	44 & 39	2.9 –4.2	1.9	---	To be Estimated
Goa	Cyclonic wind , Storm surge in cyclones	39	3.4	1.0	---	To be Estimated
Karnataka	Cyclonic wind ,Storm surge in cyclones	39	3.4 – 3.7	0.8	---	To be Estimated
Kerala	Storm surge in cyclones	39	2.3 –3.5	0.8	In 9 coast Districts	3 – 5
Lakshadweep	Storm surge in cyclones	39	Value not Measured	0.5	---	To be Estimated

(Source-National Disaster Management Division, Ministry of Home Affairs, Government of India)

Table 2 Multi Hazard Data for East Coast of India

Name of coastal State	**Vulnerable for Hazard**	**Design Cyclonic Wind**	**Probable Maximum Storm**	**Astronomical High Tide above**	**Flood Proneness**	**Tsunami Prone-ness (m)**

		(IS:875III) (m/s)	**Surge Heights (m)**	**Mean Sea Level (m)**		
Tamil Nadu	Cyclonic wind , Storm surge in cyclones	50,47,39 (PMWS- 64)	2.7 –7.0 except 11.0 near Tondi	0.5	_	7 – 10
Pondicherry	Storm surge in cyclones	50,47,39 (PMWS- 64)	3.0 –4.5	0.5	In 1 coast districts	10 (in 1 district)
Andhra Pradesh	Cyclonic wind , Storm surge in cyclones	50 (PMWS – 78)	3 – 6	0.68	In 8 coast districts	**To be estimated**
Orissa	Cyclonic wind , Storm surge in cyclones	50 & 44 (PMWS – 78)	2.7 –9.8	0.9-1.40	In 3 coast districts	**To be estimated**
West Bengal	Storm surge in cyclones , Flooding by incessant rain	50 PMWS- 78	12.0 -12.5	2.6	In 3 coast districts	**To be estimated**
Andaman & Nicobar	Tsunami	44	Value not Measured	1.0	_	3 – 6

PMWS-Probable Maximum Wind Speed
(Source-National Disaster Management Division, Ministry of Home Affairs, Government of India)

The Indian coastal belt has not recorded many severe tsunamis in the past. Waves accompanying earthquake activity have been reported over the North Bay of Bengal. During an earthquake in 1881 which had its epicenter near the Andaman's in the Bay of Bengal, tsunamis were reported. The earthquake of 1941 in Bay of Bengal caused some damage in Andaman region. This was unusual because most Tsunamis are generated by shocks which occur at or near the flanks of continental slopes. During the earthquakes of 1819 and 1845 near the Rann of Kutch, there were rapid movements of water into the sea. There is no mention of waves resulting from these earthquakes along the coast adjacent to the Arabian Sea, and it is unlikely that Tsunamis were generated. Further west, in the Persian Gulf, the 1945 Mekran earthquake (magnitude 8.1) generated Tsunami of 12 to 15 metres height. This caused a huge deluge, with considerable loss of life and property at Ormara and Pasi. The estimated height of Tsunami at Gulf of Kutchch was 15m but no report of damage is available. The estimated height of waves was about 2 metres at Mumbai, where boats were taken away from their moorings and casualties occurred.
A list showing the Tsunami that affected Indian coast in the past is given in Table-3. The information given in the Table for the first three events is sketchy and authenticity cannot be confirmed except the Tsunami of 26th December 2004.Above facts indicate the coastal region of Gujarat is vulnerable to Tsunamis from great earthquakes in Mekran coast. Earthquake of magnitude 7 or more may be dangerous. It may be noted that all earthquake do not generate Tsunami. Research is still being undertaken in this field. For the Indian region, two potential sources have been identified, namely Mekran coast and Andaman to Sumatra region.
Model generated Travel time of 26th December Tsunami is shown in Fig 4.

Fig.4:- Arrival time of first waves (sec) – 2004 12 26 Indian Ocean Tsunami Simulation(Sourse-Tsunami research programme NOAA OAR Washington)

Sr.No	Date	Remarks
1	April 12,	1762 Eq. in the Bay of Bengal generated tsunami wave of 1.8 m in coastal Bangladesh
2	August 19, 1868	Earthquake Mw 7.5 in the Bay of Bangal. Tsunami wave run-up level at Port Blair, Andaman Island 4.0 m.
3	December 31, 1881	Earthquake of magnitude Ms 7.9 in the Bay of Bengal, reported tsunami run-up level of 0.76m at Car Nicobar, 0.3m at Dublat , 0.3 m at Nagapattinam and 1.22 m at Port Blair in Andaman Island
4	1883	Karakatau, volcanic explosion in Indonessia. 1.5 m tsunami at Chennai, 0.6 m at Nagapattinam.
5	1884	Earthquake in the western part of the Bay of Bengal. Tsnamis at Port Blair & mouth of Hoogly River
6	June 26, 1941 .	Earthquake of magnitude MW 8.1 in the Andaman Sea at 12.90 N,92.5o E. Tsunamis on the east coast of India with amplitudes from 0.75 to 1.25 m. Some damage from East Coast was reported
7	November 27, 1945	Mekran Earthquake (Magnitude Ms 8.3). 12 to 15 M wave height in Ormara, 13 m at Pasni, and 1.37 m at Karachi (Pakistan) . In Gulf off Cambay of Gujarat wave heights of 11.0 m was estimated, and 2 m at Mumbai, where boats were taken away from their moorings.
8	December 26, 2004	An earthquake of rear Magnitude (MW9.3) generated giant tsunami waves in North Indian Ocean. Tsunami made extensive damage to many coastal areas of Indonesia, India, Malaysia, Maldives, Srilanka and Thailand. A trans-oceanic tsunami, observed over areas beyond the Ocean limit of origin. More than 2, 00, 000 people lost their lives in above countries which is a record.

Table 3-Tsunami that affected Indian coast in the past.(Source-National Disaster Management Department

3. Tsunami Risk in Gujarat & its Assessment.

The Tsunami risk within the Indian Ocean is quite low as compared to storm surge owing to very long return periods and the lower level of inter-plate events. Therefore, mitigative measures for protection against sea inundation due to storm surge, if suitably enhanced, could provide the most cost-effective risk mitigation measures for the region

Gujarat is prone to Tsunami risk due to its longest coastline and probability of occurrence of near and offshore submarine earthquakes in the Arabian Sea. Makran Subduction Zone (MSZ) -South West of Karachi is an active fault area which may cause a high magnitude earthquake under the sea leading to at tsunami. In past, Kandla coast was hit by a Tsunami of 12 mtrs height in 1945, due to an earthquake in the Makran fault line. Tsunami prone areas in the State include coastal villages of Kutch, Jamnagar, Rajkot, Porbandar, Bhavnagar, Anand, Ahmedabad, Bharuch, Surat, Navsari and Valsad districts.
The Hazard Risk and Vulnerability Atlas prepared by GSDMA shows (Fig. 5)the estimated inundation based on Probable Maximum Surge (PMS) at highest high tide level.
Tsunamis are extremely rare events in Gujarat. No instrumental records or damage records are available for tsunami impact in the region. Nevertheless, tsunami impact in the Gujarat region in expected to be similar to that of the worst storm surge – which occurs at a much higher frequency. It is estimated that appropriate structural mitigation measures for storm surge linked to an appropriate tsunami warning system could address much of the risk associated tsunami impact to residential populations.

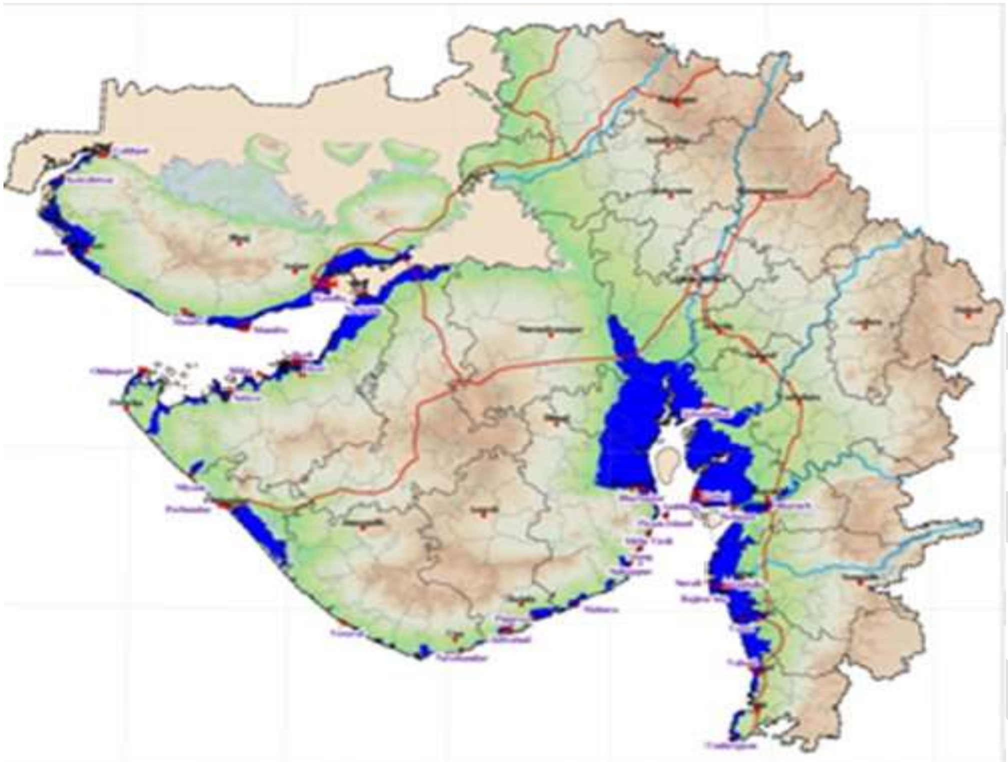

Figure 5 Gujarat Tsunami Hazard risk zones (source-Gujarat state disaster management authority)

4. Tsunami Warning System in India.

The Present status of Tsunami Warnings in India. Tsunami is very low probability event in India. As such, there are no Codal provisions for Tsunami warnings in India as yet though; there is a good seismological network in India to record any earthquake within the country and its neighbourhood. The need of a Tsunami Warning Centre (TWC) in India is now being conceptualized at the Government of India level. India Meteorological Department (IMD), is working on a proposal to set up a real time earthquake monitoring system in India. The Department of Ocean Development in collaboration with Departments of Space and IMD under Department of Science and Technology is evolving a plan of tsunami warning system in the Bay of Bengal and the Arabian Sea. The data from observing points to Warning Centre(s) will be sent through satellite links.

Specific systems called Deep Ocean Assessment and Reporting of Tsunamis (DART) using Bottom Pressure Recorder, acoustic modem, acoustic release system, battery pack bolted to platform and float action and recovery aids will be deployed. The warning centres in the Indian context could be the Emergency Operation Centre at the State & District level, which are being designed to function round the clock under the District Collector at District level and under the Chief Minister at State level

Tsunami occurs due to earth quake in ocean for detecting these activities a Network of land-based seismic stations for earthquake detection and estimation of focal parameters in the two known tsunami genic zones is a prime requirement of the warning centre. INCOIS is receiving real-time seismic data from international seismic networks as well as from India Meteorological Department (IMD) and has been detecting all earthquake events occurring in the Indian Ocean in the less than 15 minutes of occurrence. Necessary software has been installed for real-time data reception, archiving, processing and auto-location of earthquakes as well as for alert generation and automatic notification.

Present techniques of Tsunami prediction are severely limited. The only way to determine, with certainty, if an earthquake is accompanied by a Tsunami, is to note the occurrence and epicenter of the earthquake and then detect the arrival of the Tsunami at a network of tide stations. While it is possible to predict when a Tsunami will arrive at coastal locations, it is not yet possible to predict the wave height, number of waves, duration of hazard, or the forces to be expected from such waves at specific locations. Computer programmes need to be developed for this purpose. Tsunami Warning System is based on the concept that Tsunamis travel at much slower velocity (500 to 700 km per hour or 0.20 km/sec) as compared to seismic waves (6 to 8 km per second). That is seismic waves move 30 to 40 times faster than Tsunami waves. Thus, 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.

A dedicated 24 x 7 operating Tsunami Warning Centre including necessary computational, communication and technical support infrastructure as well as robust application software that facilitates data reception, display, analysis, modelling, and decision support system for generation of tsunami advisories following a standard operating procedure has been established. The warning centre continuously monitors seismic activity in the two tsunami genic source regions and sea level through the network of national and international seismic stations as well as tide gauges and bottom pressure recorders (BPR's). The monitoring of water level enables confirmation or cancellation of a tsunami

4.1 Monitoring of Sea Level.

In order to confirm whether the earthquake has actually triggered a tsunami, it is essential to measure the change in water level as near to the fault zone with high accuracy. Bottom pressure recorders (BPR) are used to detect the propagation of tsunami waves in open-ocean and consequent sea level changes. A network of Bottom Pressure Recorders (BPRs) has been installed close to the tsunami genic source regions to detect tsunami, by the National Institute of Ocean Technology (NIOT). These BPRs can detect changes of 1 cm at water depths up to 6 km. A network of tidal gauges along the coast helps to monitor progress of tsunami as well as validation of the model scenarios. Near-real time data is being received from national and international centres has been received. Necessary software for real-time reception, display and archiving of tide gauge data has been developed.

4.2 High resolution Data Base on a Bathyemetry & Coastal Topography.

Generating and updating a high resolution database on bathymetry, coastal topography, coastal land use, coastal vulnerability as well as historic data base on tsunami and storm surge to prepare and update storm surge/tsunami hazard maps. The accuracy of model predictions is directly related to the quality of the data used to create the bathymetry and topography of the model area. Coastal Bathymetry is the prime determinant of the height of the tsunami wave or storm surge as it approaches the coast. High resolution coastal bathymetry is thus the key input for various tsunami and storm surge prediction models.

5. Application of Remote Sensing & GIS for Tsunami.

One of the key components of the early warning centre is the development of application software around GIS technology that performs the following operations:

(i) Acquisition, display and analysis of real time data of seismic sensors, tide gauges and BPRs.
(ii) Generation of model scenario database for assumed earthquake parameters as well as Retrieval, Display and Analysis at the time of an event.
(iii) Generation, Display and Analysis of Bathymetric Data, Coastal Topographic Data and Vulnerability Maps.
(iv) Decision support system for generation of tsunami advisories following a standard operating procedure.
(v) Data warehousing, Data Mining and Data Dissemination

For the assessment of damage after Tsunami good help is achieved by remote sensing and GIS. In the first stage, general damage information, such as tsunami inundation limits, can be obtained promptly using an analysis combined with ground truth information in GIS.

In the second stage, detailed damage interpretations can beanalysed; i.e., classification of the building damage level. Recently, the quality of commercial satellite images has improved. These images help us clarify, i.e., whether a house was washed away or survived; they can even classify more damage levels.

The third stage combines the damage and hazard information obtained from a numerical simulation, such as the tsunami inundation depth. The damage data are compiled with the tsunami hazard data via GIS. Finally, a tsunami vulnerability function can be developed. This function is a necessary tool for assessing future tsunami risk. Recent advances in remote sensing technologies have expanded the capabilities of detecting the spatial extent of tsunami-affected areas and damage to structures.

6. CONCLUSION

Due rapid growth of industry and cities on coastal shores. Now a day's coastal hazard are unavoidable occurrence and it is not possible to control by human efforts. Humans are making best try to prevent it becoming DISASTER. Remote sensing and GIS inputs are useful and used to save innocent lives and for impact assessment to infrastructure and properties. Remote sensing and GIS are used operationally for early warning and monitoring of cyclones, tsunami which are often destruct coastal areas. It is required to appropriately choose RS data with required spatial and temporal resolution for information extraction and integrating it with field survey data using GIS framework. This paper has provided insight about the possible applications of remote sensing and GIS in coastal hazards.

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