

TSUNAMI EARLY WARNING SYSTEM FOR PAKISTAN

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ABSTRACT: Keeping in view the present scenario of extreme events of natural hazards and future trends based on numerical models, it is the need of hour to invest in coping mechanisms from natural hazards.

After the tsunami devastated the lives of hundreds of thousands in South Asia, including some of its poorest citizens, the world responded immediately to assess the technological and infrastructure requirements for establishing Tsunami Early Warning System for countries bordering Indian Ocean.

Pakistan has the history of being affected by a Tsunami in 1945 which resulted around 4000 thousand casualties along Makran coast. Accordingly PMD put forward a project “up gradation and strengthening of Seismic Network” to the government with the total cost of Rs. 200 m. The same has been approved and is being implemented from 1st July 2005. This system will enable PMD to monitor all seismic events and pin-point the exact centre within minutes of their occurrence. Moreover, Government has appointed PMD as focal agency to receive Tsunami Alerts from regional Tsunami Warning Centre, Japan. As such PMD will have two different sources of information to issue Tsunami Alert for the safety of coastal areas of Pakistan.

The causes and physical parameters of tsunami are also discussed in this paper that may help in early warning of this killer ocean wave. Since the world was appalled by the huge loss of life and massive destruction caused by the Indian Ocean tsunami of 26 December 2004, therefore a brief about this tragic event is also reported. The history of tsunamis in South Asia in general and in Pakistan & Arabian Sea in particular is also documented.

Finally the components of Tsunami Early Warning System have been discussed and few recommendations for disaster preparedness have been highlighted to enable vulnerable communities to re-act on early warnings so that targeted benefits could be achieved from early warnings.

1. Introduction:

On December 26, 2004, a devastating severe earthquake (magnitude 9.0) occurred off the western coast of Sumatra in the Indian Ocean. The earthquake was caused by the release of stresses accumulated as the Burma tectonic plate overrides the India tectonic plate. Movement of the seafloor due to the earthquake generated a tsunami, or seismic sea wave, that affected coastal regions around the Indian Ocean. The northwestern Sumatra coastline in particular suffered extensive damage and loss of life. The world was appalled by the huge loss of life and massive destruction caused by the Indian Ocean tsunami of 26 December 2004.

The Indonesian province of Aceh was hit hardest by the earthquake and tsunamis of December 26, 2004. Aceh is located on the northern tip of the island of Sumatra. Early Western media attention was focused on Sri Lanka and Thailand, even though the earthquake epicenter was closer to Aceh, and the largest waves struck the northwestern coast of Sumatra. On Decemebr 29, estimates of the death toll in Indonesia were over 80,000—more than half the

global total. The town of Lhoknga, on the west coast of Sumatra near the capital of Aceh, Banda Aceh, was completely destroyed by the tsunami, with the exception of few buildings in the city's center.

Satellites continued to acquire imageries of areas severely damaged by the tsunami of December 26, 2004. This image of Meulaboh, Indonesia, was collected on January 7, 2005, by DigitalGlobe's QuickBird satellite. Meulaboh is located on the coast of Sumatra, roughly 150 kilometers (93 miles) from the epicenter of the magnitude 9.0 earthquake that generated the tsunami.

The images show how badly the tsunami washed over a narrow peninsula, eroding the beach and destroying many of the town's buildings.

The high-resolution satellite images, acquired by Space Imaging's Ikonos satellite, show Lhoknga before and after the earthquake and Tsunami depict that almost all the trees, vegetation, and buildings in the area were washed away. Low-lying agricultural areas remained covered with water four days after the disaster, and sand on the nearby beaches was completely removed. The wave height might have exceeded 15 meters (50 feet) when it struck the shore.

2. Basics about Tsunamis

The word Tsunami (pronounced soo-nah'-mee) is composed of the Japanese words "tsu" (means harbor) and "nami" (means "wave"). The phenomenon we call tsunami is a series of large waves of extremely long wavelength and period usually generated by a violent, impulsive undersea disturbance or activity near the coast or in the ocean.

When a sudden displacement of a large volume of water occurs, or if the sea floor is suddenly raised or dropped by an earthquake, big tsunami waves can be formed by forces of gravity. The waves travel out of the area of origin and can be extremely dangerous and damaging when they reach the shore.

The tsunami waves are completely unrelated to the astronomical tides - which are caused by the extraterrestrial, gravitational influences of the moon, sun, and the planets. Thus, the Japanese word "tsunami", meaning "harbor wave" is the correct, official and all-inclusive term. It has been internationally adopted because it covers all forms of impulsive wave generation.

2.1 The Science of Tsunami

There are many causes of tsunamis but the most prevalent is earthquake. In addition, landslides, volcanic eruptions, explosions also generate Tsunamis.

2.2 Tsunamis generated by earthquakes

By far, the most destructive tsunamis are generated from large, shallow earthquakes with an epicenter or fault line near or on the ocean floor. These usually occur in regions of the earth characterized by tectonic subduction along tectonic plate boundaries. The high seismicity of such regions is caused by the collision of tectonic plates. When these plates move past each other, they cause large earthquakes, which tilt, offset, or displace large areas of the ocean floor from a few kilometers to as much as a 1,000 km or more. The sudden vertical displacements over such large areas, disturb the ocean's surface, displace water, and generate destructive tsunami waves.

To generate a tsunami,

- earthquakes must occur underneath or near the ocean,
- be large and create movements in the sea floor

The waves can travel great distances from the source region, spreading destruction along their path. For example, the Great 1960 Chilean tsunami was generated by a magnitude 9.5 earthquake that had a rupture zone of over 1,000 km. Its waves were destructive not only in Chile, but also as far away as Hawaii, Japan and elsewhere in the Pacific.

It should be noted that not all earthquakes generate tsunamis. Usually, it takes an earthquake with a Richter magnitude exceeding 7.5 to produce a destructive tsunami.

2.3 Tsunamis caused by asteroids, meteorites or man-made explosions

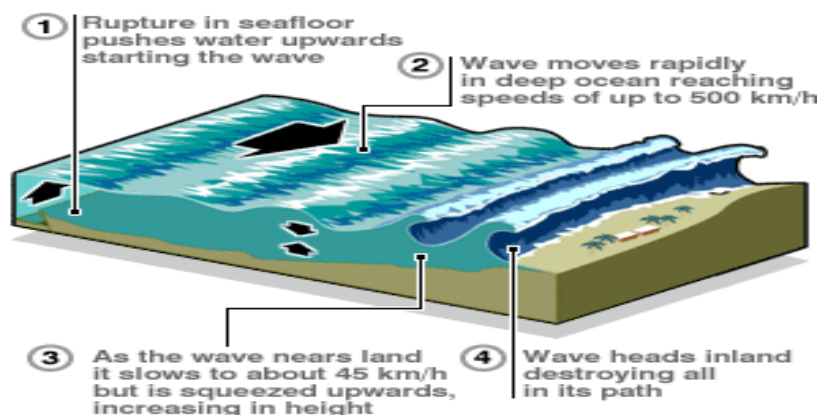
Fortunately, for mankind, it is indeed very rare for a meteorite or an asteroid to reach the earth. No asteroid has fallen on the earth within recorded history. Most meteorites burn as they reach the earth's atmosphere. However, large meteorites have hit the earth's surface in the distant past. This is indicated by large craters, which have been found in different parts of the earth. Also, it is possible that an asteroid may have fallen on the earth in prehistoric times - the last one some 65 million years ago during the Cretaceous period. Since evidence of the fall of meteorites and asteroids on earth exists, we must conclude that they have fallen also in the oceans and seas of the earth, particularly since four fifths of our planet is covered by water. The fall of meteorites or asteroids in the earth's oceans has the potential of generating tsunamis of cataclysmic proportions. Scientists studying this possibility have concluded that the impact of moderately large asteroid, 5-6 km in diameter, in the middle of the large ocean basin such as the Atlantic Ocean, would produce a tsunami that would travel all the way to the Appalachian Mountains in the upper two-thirds of the United States. On both sides of the Atlantic, coastal cities would be washed out by such a tsunami. An asteroid 5-6 kilometers in diameter impacting between the Hawaiian Islands and the West Coast of North America, would produce a tsunami which would wash out the coastal cities on the West coasts of Canada, U.S. and Mexico and would cover most of the inhabited coastal areas of the Hawaiian islands. Conceivably tsunami waves can also be generated from very large nuclear explosions. However, no tsunami of any significance has ever resulted from the testing of nuclear weapons in the past. Furthermore, such testing is presently prohibited by international treaty.

2.4 Tsunamigenesis

The mechanism how does tsunami energy travels across the ocean is called Tsunamigenesis.

Once a tsunami has been generated, its energy is distributed throughout the water column, regardless of the ocean's depth. A tsunami is made up of a series of very long waves. The waves will travel outward on the surface of the ocean in all directions away from the source area, much like the ripples caused by throwing a rock into a pond. The wavelength of the tsunami waves and their period will depend on the generating mechanism and the dimensions of the source event.

If the tsunami is generated from large earthquake over a large area, its initial wavelength and period will be greater. If the tsunami is caused by a local landslide, both its initial wavelength and period will be shorter. The period of the tsunami waves may range from 5 to 90 minutes. The wave crests of a tsunami can be a thousand km long, and from a few to a hundred kilometers or more apart as they travel across the ocean.



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On the open ocean, the wavelength of a tsunami may be as much as two hundred kilometers, many times greater than the ocean depth, which is on the order of a few kilometers. In the deep ocean, the height of the tsunami from trough to crest may be only a few centimeters to a meter or more - again depending on the generating source. Tsunami waves in the deep ocean can travel at high speeds for long periods of time for distances of thousands of kilometers and lose very little energy in the process. The deeper the water, the greater the speed of tsunami waves will be. For example, at the deepest ocean depths the tsunami wave speed will be as much as 800 km/h, about the same as that of a jet aircraft. Since the average depth of the Pacific ocean is 4000 m (14,000 feet), tsunami wave speed will average about 200 m/s or over 700 km/h (500 mph). At such high speeds, a tsunami generated in Aleutian Islands may reach Hawaii in less than four and a half hours. In 1960, great tsunami waves generated in Chile reached Japan, more than 16,800 km away in less than 24 hours, killing hundreds of people.

3. Important Factors of tsunami causing destruction

There are three important factors causing destruction comprising:

- Inundation,
- Wave impact on structures, and
- Erosion.

Strong, tsunami-induced currents lead to the erosion of foundations and the collapse of bridges and seawalls. Flotation and drag forces move houses and overturn railroad cars.

Considerable damage is caused by the resultant floating debris, including boats and cars that become dangerous projectiles that may crash into buildings, break power lines, and may start fires. Fires from damaged ships in ports or from ruptured coastal oil storage tanks and refinery facilities, can cause damage greater than that inflicted directly by the tsunami. Of increasing concern is the potential effect of tsunami draw down, when receding waters uncover cooling water intakes of nuclear power plants.

4. Physical parameters of Tsunami helpful in mitigation / early warning.

Tsunamis arrive at a coastline as a series of successive crests (high water levels) and troughs (low water levels) - usually occurring 10 to 45 minutes apart. As they enter the shallow waters of coastlines, bays, or harbors, their speed decreases to about 50-60 km/h.

For example, in 15 m of water the speed of a tsunami will be only 45 km/h. However 100 or more kilometers away, another tsunami wave travels in deep water towards the same shore at a much greater speed, and still behind it there is another wave, traveling at even greater speed.

As the tsunami waves become compressed near the coast, the wavelength is shortened and the wave energy is directed upward - thus increasing their heights considerably. Just as with ordinary surf, the energy of the tsunami waves must be contained in a smaller volume of water, so the waves grow in height. Even though the wavelength shortens near the coast, a tsunami will typically have a wavelength in excess of ten kilometers when it comes ashore. Depending on the water depth and the coastal configuration, the waves may undergo extensive refraction - another process that may converge their energy to particular areas on the shore and thus increase the heights even more.

Even if a tsunami wave may have been 1 meter or less in the deep ocean, it may grow into a huge 30-35 meter wave when it sweeps over the shore. Thus, tsunami waves may smash into the shore like a wall of water or move in as a fast moving flood or tide - carrying everything on their path. Either way, the waves become a significant threat to life and property.

If the tsunami waves arrive at high tide time, or if there are concurrent storm waves in the area, the effects will be cumulative and the inundation and destruction even greater. The historic record shows that there have been many tsunamis that have struck the shores with devastating force, sometimes reaching heights of more than 30-50 meters. For example, the 1946 tsunami generated by an earthquake off Unimak island in Alaska's Aleutian Islands, reached heights of more than 35 meters, which destroyed a reinforced concrete lighthouse and killed its occupants.

Finally, the maximum height a tsunami reaches on shore is called the runup. It is the vertical distance between the maximum height reached by the water on shore and the mean sea level surface. Any tsunami runup over a meter is dangerous. The flooding by individual waves will typically last from ten minutes to a half-hour, so the danger period can last for hours. Tsunami runup at the point of impact will depend on how the energy is focused, the travel path of the tsunami waves, the coastal configuration, and the offshore topography. Small islands with steep slopes usually experience little runup - wave heights there are only slightly greater than on the open ocean. This is the reason that islands with steep-sided fringing or barrier reefs are only at moderate risk from tsunamis.

5. Behavior of Tsunami after Landfall

After runup, part of the tsunami energy is reflected back to the open ocean. In addition, a tsunami can generate a particular type of wave called edge waves that travel back-and forth, parallel to shore. These effects result in many arrivals of the tsunami at a particular point on the coast rather than a single wave. Because of the complicated behavior of tsunami waves near the coast, the first runup of a tsunami is often not the largest, emphasizing the importance of not returning to a beach several hours after a tsunami hit.

5.1 Locally generated tsunamis are more dangerous

A locally generated tsunami may reach a nearby shore in less than ten minutes. There is not sufficient time for the Pacific Tsunami Warning Center or for local authorities to issue a warning. For people living near the coast, the shaking of the ground is a warning that a tsunami may be imminent. For tsunamis from more distant sources, however, accurate warnings of when a tsunami might arrive are possible because tsunamis travel at a known speed.

6. Tsunami Prone Areas of the World

Tsunamis are disasters that can be generated in all of the world's oceans, inland seas, and in any large body of water. Each region of the world appears to have its own cycle of frequency and pattern in generating tsunamis that range in size from small to the large and highly destructive events. Most tsunamis occur in the Pacific Ocean and its marginal seas. The reason is that the Pacific covers more than one-third of the earth's surface and is surrounded by a series of mountain chains, deep-ocean trenches and island arcs called the "ring of fire" - where most earthquakes occur (off the coasts of Kamchatka, Japan, the Kuril Islands, Alaska and South America).

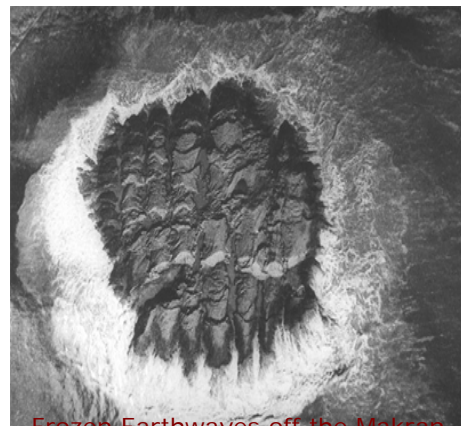
Although not as frequent, destructive tsunamis have also been generated in the Atlantic and the Indian Oceans, the Mediterranean Sea and even within smaller bodies of water, like the Sea of Marmara, in Turkey. In 1999, a large earthquake along the North Anatolian Fault zone, generated a local tsunami, which was particularly damaging in the Bay of Izmit. In the last decade alone, destructive tsunamis have occurred in Nicaragua (1992), Indonesia (1992, 1994, 1996), Japan (1993), Philippines (1994), Mexico (1995), Peru (1996, 2001), Papua-New Guinea (1998), Turkey (1999), and Vanuatu (1999).

6.1 History of Tsunamis in Pakistan/Arabian Sea

Though rare and relatively unheard of, tsunamis have struck the shores of Pakistan in the past. The deadliest was in 1945 which originated off the Makran coast in Pakistan and the earliest known tsunami occurred in the Bay of Bengal in 1762, caused by an earthquake on Myanmar's, Arakan Coast. Detail of Tsunami occurred in 1945 is appended below.

The earthquake occurred at 21:56 UTC (02:56 PST). Its magnitude was 8.3 and was centred at;

87.1 kilometres SSW of Churi (Balochistan), Pakistan,
97.6 kilometres SSW of Pasni (Balochistan), Pakistan,
98.5 kilometres SE of Gwadar (Balochistan), Pakistan,
408 kilometres W of Karachi (Sindh), Pakistan



Frozen Earthwaves off the Makran Coast (Photograph of the area taken after the event)

- The tsunami reached a height of 40 feet in some Makran ports and caused great damage to the entire coastal region.
- The fishing village of Khudi, some 30 miles west of Karachi, was completely obliterated. All the inhabitants and their huts were washed away.

- Total causality was reported as around 4000.
- The towns of Pasni and Ormara were badly affected. Both were reportedly "underwater" after the tsunami.
- At Karachi, the tsunami arrived from the direction of Clifton and Ghizri. It ran along the oil installations at Keamari and flooded a couple of compounds. The waves were 6.5 feet high in Karachi.

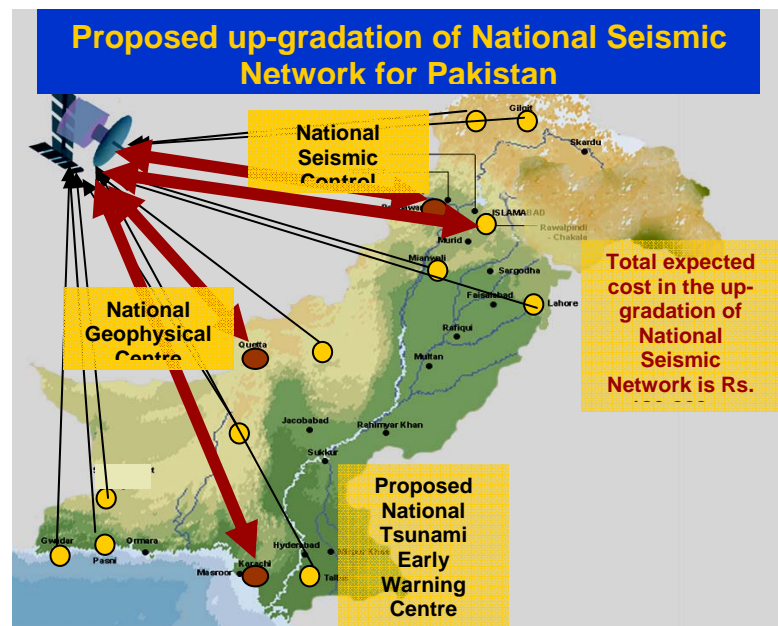
6.2 Major Tsunamis in South Asia

Major Tsunamis in South Asia

Date	Location
1524	Near Dabhol, Maharashtra
02 April 1762	Arakan Coast, Myanmar
16 June 1819	rann of kachchh Gujrat
31 October 1847	Great Nicobar Island
31 December 1881	Car Nicobar Island
26 August 1883	Krakatoa volcanic eruption
28 November 1945	Makran coast Balochistan

7. Tsunami Early Warning System in Pakistan

Pakistan has the history of being affected by a Tsunami in 1945 which resulted around 4000 casualties along Makran coast. Moreover, the aftermaths of deadliest Tsunami disaster associated with the great Sumatra Earthquake of 26th December 2004, the need for the establishment of TEWS became inevitable. The government of Pakistan agreed in principle for the Establishment of a Tsunami Early Warning System (TEWS) at Karachi in order to protect the lives of masses and coastal areas of vital geopolitical and economic importance which include metropolitan city of Karachi, strategic naval installations and newly emerging port city of Gwadar. Being the Lead Agency for the Establishment of TEWS in Pakistan, Phase-I of the project entitled "Up gradation and Strengthening of Seismic Network of Pakistan" has been approved by the government during May 2005 with an estimated cost of Rs. 193.574 million. Under this project, 15 broad band Seismic Stations alongwith 50 short period Seismic Stations would be established giving complete coverage especially to the coastal areas of



Pakistan for the recording of offshore Earthquakes that can generate a Tsunami. Besides recording online Seismic data, 50-60 strong motion accelerographs would also be installed in major cities for recording acceleration produced by felt earthquake with a view to formulating a building code for the country. Implementation of the project has started with effect from 01-07-2005.

Major Components of this system include;

- Efficient National Seismic Network
- Network of at-least 5-8 moored buoys
- Linkage to Regional & Global Tsunami Warning Centers
- Capacity Building

This project is the first step towards the establishment of Tsunami Early Warning System in Pakistan. During next phase, 5-8 moored Buoys will be installed in Arabian Sea with the collaboration of international community and Close linkage to regional and international Tsunami Warning Centers will be established.

Presently, PMD is also acting as focal agency to receive Tsunami Alerts from regional Tsunami Warning Centre, Japan. As such PMD will have two different sources of information to issue Tsunami Alerts for the safety of coastal areas of Pakistan.

8. Benefits of the establishment of TWS

- Improved Seismological Services to enhance our capacity in fulfilling our national/ international commitments & obligations.
- Generated seismological and strong motion data (ground surface acceleration) to facilitate in devising building code for the country on micro-scale.
- Sea wave and additional Met. Data generated by Moored Buoys will ensure safety of marine activities and its global exchange will help in fulfilling international obligations as desired under GCOS program.
- Existing and future seismic data so generated to serve as data-bank for the promotion & safety of our socio-economic activities especially the housing and Insurance industries.
- Above all, it will provide sufficient lead time in issuing necessary alerts / warnings against possible impending Tsunami disasters facilitating concerned govt. functionaries to undertake coordinated disaster preparedness and mitigation activities

9. Conclusion

Natural disaster prevention and mitigation are developmental issues. Hence, resources for the provision of meteorological and hydrological warning systems should be regarded as an investment rather than expenditure. Government of Pakistan is giving priority to invest in the future. However, prevention from natural disasters is not a localized issue and it should be coped through joint efforts with major investment share from developed world.

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