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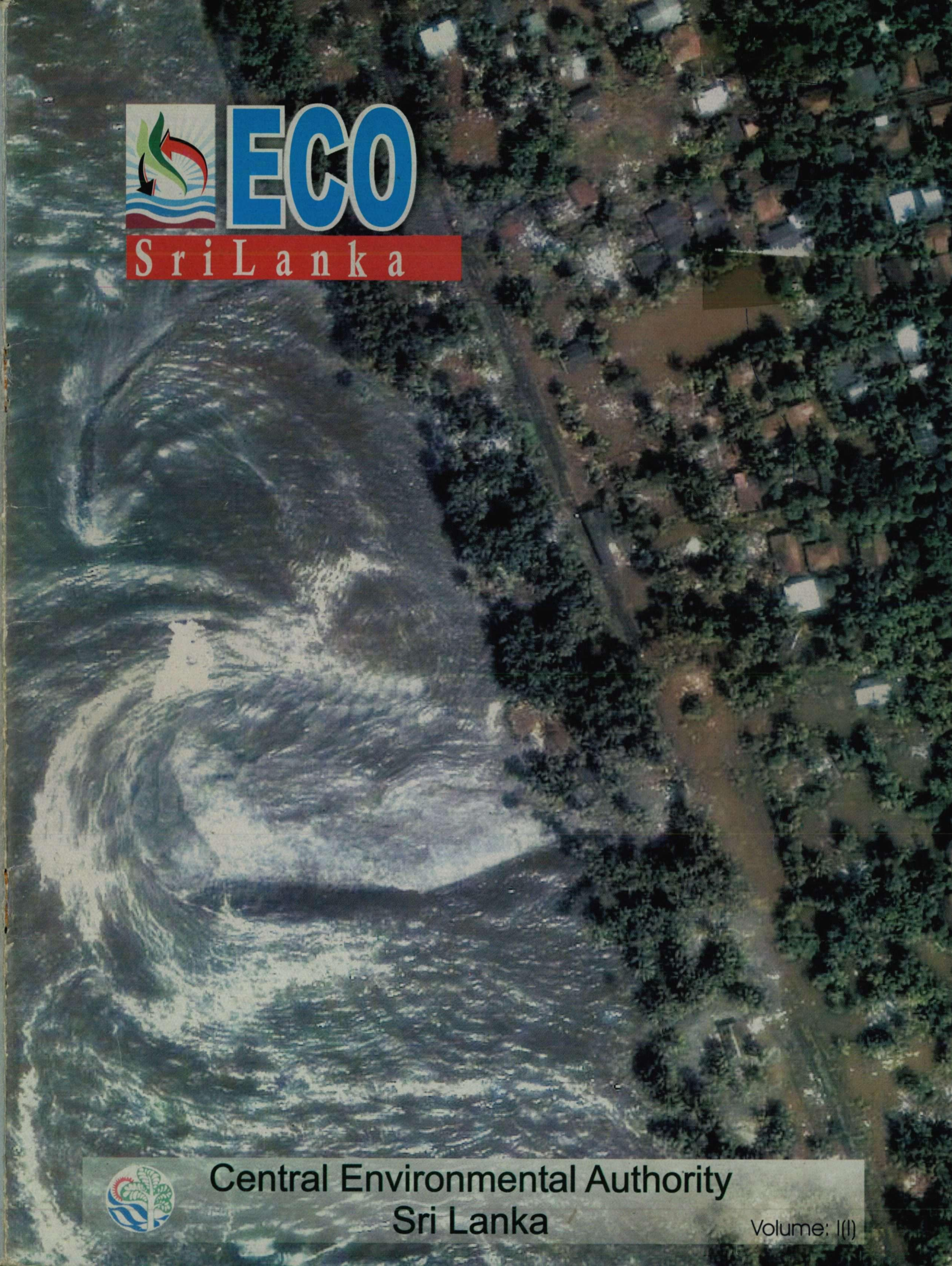

ECO Sri Lanka

Central Environmental Authority
Sri Lanka

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2005

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Functions of the
Central Environmental Authority

The National Environmental Act No.47 of 1980 and its subsequent amendments entrusts the Central Environmental Authority with the following powers and functions
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Its Vision

A healthy, productive and pleasant environment that meets the aspirations of the present and future generations of Sri Lanka

Its Mission

To protect and enhance the quality of the environment for the people of Sri Lanka through pollution control, natural resources management and environmental education based on our technical expertise and commitment

CENTRAL ENVIRONMENT AUTHORITY
BOARD OF DIRECTORS 2004/2005

EDITORIAL NOTE

The inaugural issue of Eco-Sri Lanka comes out at a time when the country is in the process of recovering from an unprecedented and devastating natural disaster – the tsunami. It was therefore, thought it highly appropriate to dedicate this issue to the theme of tsunami, its causes and effects.

This issue of Eco-Sri Lanka, accordingly contains a small collection of papers by a few individuals who are highly knowledgeable in their own fields of specialization. The theme paper by Ranjith Galappaththi provides an over view of the problem of tsunami. Other papers cover different aspects of it including the impacts on coastal ecosystems and fisheries. The paper by Ranaviraja deals more with policy aspects and focuses on the creation of green belt along the coast line.

The opinions expressed in different papers represent the independent opinions of the authors. Neither the Editors nor the Central Environmental Authority holds any responsibility for these views. As founder editors we wish Eco-Sri Lanka long life and sustainability. It certainly fulfils a long felt national need.

C.M. Madduma Bandara
S.B. Kotagama

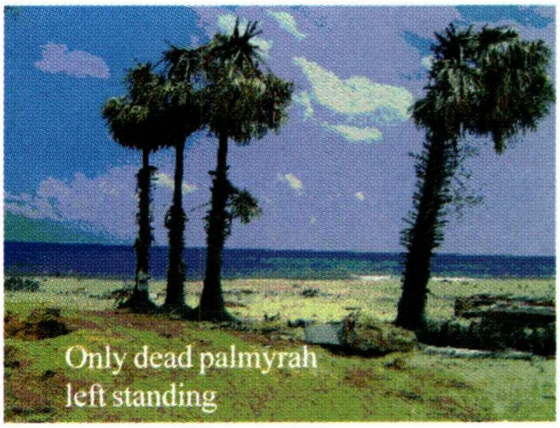
LEARNING ABOUT TSUNAMIS

Ranjit Galappatti

*Former Professor of Civil Engineering, University of Peradeniya;
Former Chief Technical Advisor, DANIDA Surface Water Simulation Modelling Programme, Bangladesh;
Former Managing Director, Lanka Hydraulic Institute.*

Introduction

The tsunami which struck several Indian Ocean countries on 26 December 2004 with unprecedented ferocity, was totally unexpected. Although smaller tsunamis had been experienced in the Indian Ocean in the past, these had affected only countries with shorelines close to the epicentre of the undersea earthquake that triggered them. It is generally known that earthquakes occur when tectonic plates which make up the earth's crust, press and rub against one another. Great earthquakes occur mostly at plate boundaries, although smaller quakes do occur along faults that are found within a plate.


Only dead palmyrah left standing

The only tsunami to be recorded on the shores of Sri Lanka were the waves generated by the underwater volcanic explosion that in 1883 destroyed the island of Krakatoa which lay in the narrow strip of sea between the islands of Sumatra and Java. The brunt of this violent upheaval under the sea (the explosion was heard in Sri Lanka) was taken by the adjacent coasts of Java and Sumatra, where tsunami waves as high as 35m were experienced. The waves that reached Sri Lanka were very small (of the order of 1m height), and only a few deaths were recorded, mainly among people who ventured out to collect fish stranded on the sea bed by the receding water. There are no other tsunamis on record in Sri Lanka, although it is likely that other, smaller tsunamis generated far away had reached our shores and passed unnoticed. The historical story of the floods that led to Vihara Maha Devi being cast out to sea by her father the King of Kelaniya 2000 years ago, could well be describing a tsunami event.

The horrific events of 26 December are marked indelibly on those who were directly in the path of the tsunami wave and still survived. Their experiences were brought very close, to even those were far away from the affected areas, by vivid television images. In order to put these events behind us and move forward, it is necessary to reach some understanding of what took place and whether these events are likely to be repeated in our lifetime or that of our children. This process has been made very difficult by the repeated instances of panic created by those who have made predictions of new disasters and the media who have sought to publicise these claims without regard to the effect they might have

THE RICHTER SCALE

M=1 to 3: Recorded on local seismographs, but generally not felt

M=3 to 4: Often felt, no damage

M=5: Felt widely, slight damage near epicentre

M=6: Damage to poorly constructed buildings etc within 10's km

M=7: "Major" earthquake, causes serious damage up to ~100 km (recent Taiwan, Turkey, Kobe, Japan, and California earthquakes)

M=8: "Great" earthquake, great destruction, loss of life over several 100 km (1906 San Francisco)

M=9: ***Rare Great Earthquake***, major damage over a large region over 1000 km (Chile 1960, Alaska 1964, and Sumatra 2004)

The Richter scale is logarithmic. An increase of one point in the scale signifies a ten times increase in the amount of "shaking" and 32 times increase in the amount of energy released.

on the coastal population who are still in a very fragile state of mind. On the other hand, the massive earthquake of 28th March was large enough to have generated another destructive tsunami. The fact that it did not is also an indication of how rare the event of 26th December really was.

Many claims made in the media are based on selective and extreme misinterpretation of scientific theories, which regularly feed the fears of a traumatised nation. It is hoped that this article and the other related articles in this publication will help members of the public evaluate these claims more soberly and critically.

Causes

The fact that an extremely powerful undersea earthquake caused the tsunami is widely known. What not widely understood is that earthquakes on land do not give rise to tsunamis and that only an extremely small proportion of all undersea earthquakes give rise to tsunamis. The likelihood of being struck by another tsunami in the near future is in the minds of many people and the government. It is therefore important to put matters into proper perspective by stating a few facts:

a) Large tsunamis (what we experienced was probably the most destructive ever recorded) are produced by "megathrust" events where a large area of the sea bed is lifted suddenly due to a massive earthquake.

b) These megathrust events all occur in areas of plate convergence where an ocean plate slides under a continental plate, a process known as subduction.

c) There are only two such convergence zones in the Indian Ocean, the longer of these is the fault zone where the Indian Plate pushes under the Burma Plate (a part of the European Plate) along a line that runs in an arc west and south of Indonesia and north across the Andaman sea. The very deep valley that is found in the sea bed alongside this boundary is known as the Sunda Trench.

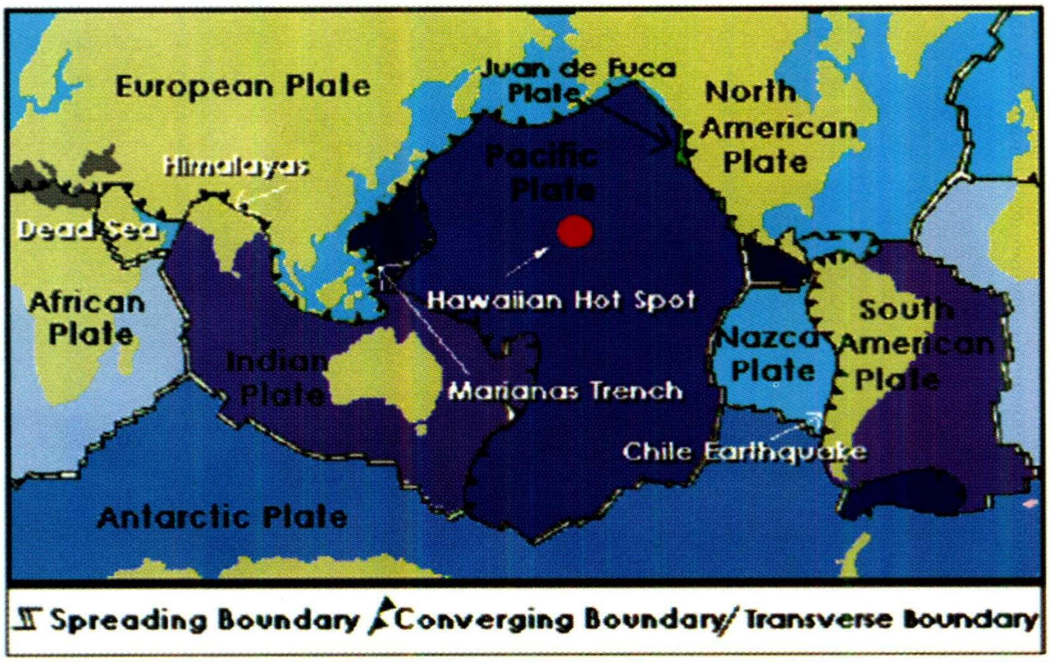


Figure 1: Types of Tectonic Plate Boundaries[1]

[1] http://www.extremescience.com/Plate Tectonicsmap.htm

d) Geologists believe that the Indian plate has been slowly breaking into two for the last 8 million years and some geologists consider them to be two separate plates (the Indian & Australian plates), but the boundary between the two parts is not a converging boundary that could give rise to a tsunami.

e) It is widely held that the only plate convergence zone which could set off a tsunami able to reach Sri Lanka is the area just west of Sumatra. Such a tsunami will take 2 hours to reach the east coast of Sri Lanka.

f) The magnitude 9 earthquake of December 2004 was the strongest ever recorded under the Indian Ocean. A repeat earthquake in the same area of such a magnitude is very unlikely in the foreseeable future. However, there was a magnitude 8.7 earthquake further along to the south east of the same fault line on 28 March 2005. The occurrence of successive 'great' earthquakes only three months apart in the same area is unprecedented. Though some geologists had suggested that the Sundar Trench had not released all its energy on 26 December, the size of this 'aftershock' was nevertheless unexpected.

g) The 28 March earthquake did generate a small tsunami which was detected in Sri Lanka. Small wave heights were detected by instruments in Kirinda. In this context it should be remembered that this magnitude 8.7 event had 50% of amplitude and 35% of the energy of the magnitude 9 event of 26 December 2004.

Figures 2 show the relative positions of the areas affected by the two great earthquakes of 26 December and 28 March. Figure 3 also shows the areas affected by historical earthquakes in 1833 and 1861. The earthquake of 28 March did generate a tsunami of height 3m off Sumatra and detected as a 0.25m wave in Colombo. It should also be mentioned that the there is no record of events of 1833 and 1861 being felt in Sri Lanka.

The Tsunami Wave in Sri Lanka

Figure 2: Two Great Earthquakes

The sudden vertical movement of a large area of sea bed causes a broad, shallow group of waves in the water directly above. These waves travel extremely quickly away from the point (or in the case of the 26 December event a 1200km long area of disturbance) in very deep water. These waves can travel at the speed of a jet aircraft. The waves will slow down quite significantly when they reach the shallow continental shelf and slow even further when they approach the shore. As these waves slow down they become taller and steeper as illustrated in Figure 3. This figure gives you an idea of how the tsunami wave group would have approached the east coast of Sri Lanka. What we term loosely as "the wave" is a group of waves of which we are mostly interested in the largest wave that caused most of the destruction. It can also be seen that when one part of the wave is high above the normal level of the sea another part is well below sea level. This is the reason that the sea appeared to withdraw far from the shore in many places.

After reaching Sri Lanka, the wave wraps (refracts) around the island. This can be understood by seeing how as one part of the wave is slowed down by the south east coast, the wave further to the south is still in deep water and will continue to move quickly and overtake the northern part of the wave which has already reached the east coast. Figure 4 shows 6 snapshots taken from a simulation[2] of how the tsunami wave approaches Sri Lanka and refracts around it while meeting waves reflected from the land. High water levels are shown in red while blue shows water levels below normal sea level. The time of each snapshot in given above in Sri Lanka Standard Time. The tsunami was initiated at 06:58 Sri Lanka time off Sumatra.

Figure 5 is also able to explain why the tsunami wave hit the East and South East coastline without any apparent warning (at about 9.00 am) and why very complex phenomena are reported from the South and West coasts which were hit by the largest wave any time between 9.30 am and 11.30 am. It is possible to say that if the sea recedes far away from the shore exposing the sea bed, it is time to run to high ground because a large wave is likely to come after 10-20 minutes. However, this is not always the case. On most of the East coast of Sri Lanka, the largest wave came without warning. In the rest of the country the largest wave was the first, second, third or even the fourth wave and usually after the sea receded several hundred metres. Thus it is not possible to generalise.

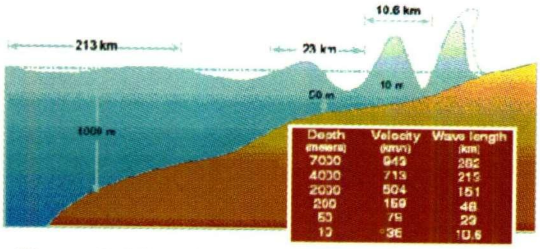


Figure 3: Wave Propagation & Transformataion

Tsunami Damage

The extent of physical damage due to the tsunami wave depended on the following:

1) Characteristics of the wave reaching land;
2) Topography of the land in the path of the wave;
3) Resistance to overland flow (eg. dense vegetation or dense housing) and
4) Ability to absorb the flood (large estuaries and lagoons).

The number of lives lost depended not only on the above, but even more on whether there

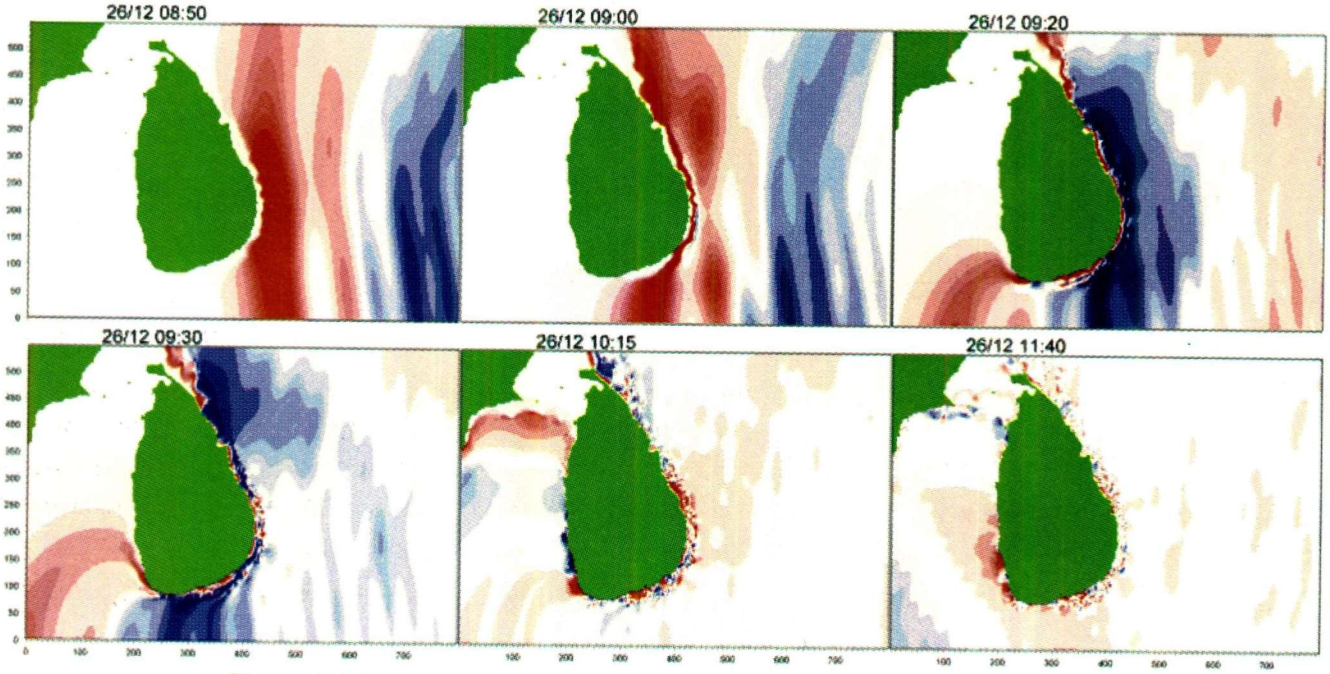
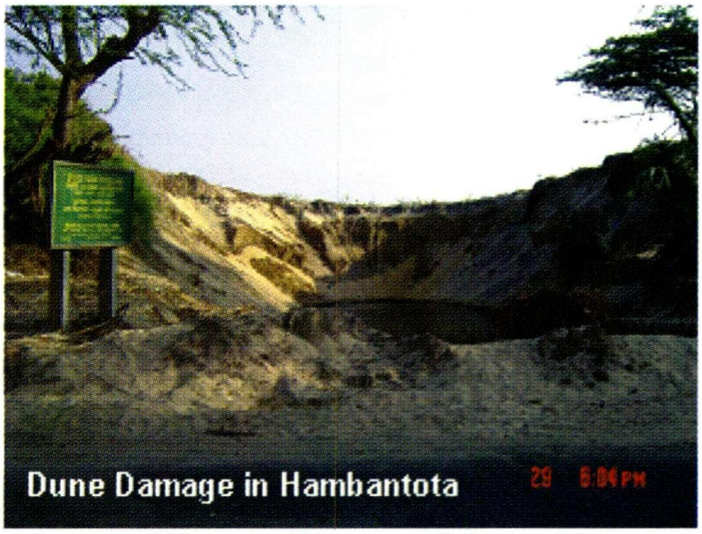


Figure 4: A Computer simulation of Tsuname Waves approaching Sri Lanka

[2] Source: DHI Water & Environment, http://www.dgi.dk

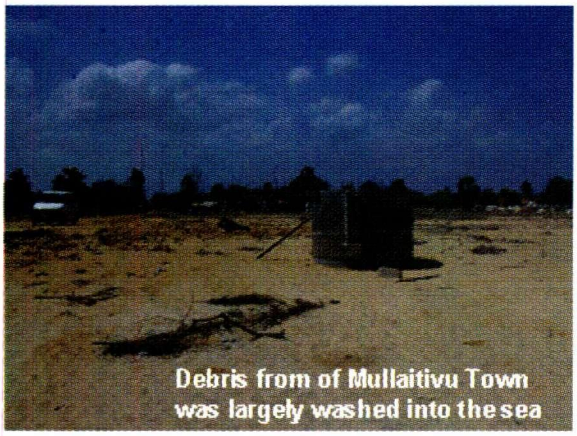
was any warning and whether there was shelter or a high point that people could run to and even whether a person could swim.

The properties of the wave approaching landfall are also dependent on factors other than those mentioned earlier. These are the actual shape and alignment of the coastline (bays and large estuaries were more vulnerable) as well as the shape of the seabed (bathymetry) including the presence of reefs.

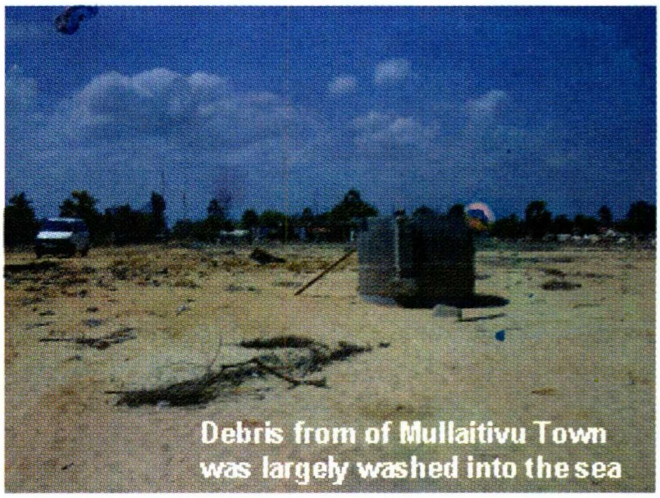


Dune Damage in Hambantota

The tall sand dunes found along long stretches of the south east and the far northeast coasts were very effective in withstanding the tsunami wave. The wave penetrated all natural gaps and some low points in the dunes, as well as all points where the dunes had been breached by human action for various purposes. Nature makes gaps in the dune system to allow rivers, tidal creeks and lagoons to drain into the sea; these are unavoidable. The tsunami wave entered through every one of these gaps and often caused lateral flooding of lands further inland that would otherwise have been protected by the dune system.


Debris from of Mullaitivu Town was largely washed into the sea

Small houses and buildings were often unable to withstand the force of the water, while large strong buildings with concrete frameworks were able to withstand the force of the water with only damage to their ground floor. The surprisingly large amount of debris left by the destruction was strewn around on the ground, washed into lagoons and/or washed back into the sea by the returning water. In the northeastern town of Mullaitivu which was completely destroyed, the returning water washed everything into the sea including large quantities of sand form the beach, even exposing culverts that had remained buried since the cyclone of 1964.


Debris from of Mullaitivu Town was largely washed into the sea

The force of the water was absorbed by large stands of dense vegetation, reducing the destruction behind them. Coconut trees did not provide such shelter, but unlike other vegetation, neither were they destroyed by the flowing water, even if they were fully submerged for a brief period. Palmyrah trees however appear to have been destroyed easily by immersion in salt water. While the presence of mangroves had partially protected some estu aries, it must be pointed out that mangroves did not occur naturally on exposed coastlines in Sri Lanka and neither can they be grown in the face of such an energetic wave climate.

Much has been written about the human cost of this catastrophe. The barest statistics are shown in Figure 5.

The recent Rapid Green Assessment carried out by the Ministry of Environment revealed that although severe damage had been inflicted on the built environment, infrastructure and on livelihoods, the ecosystem damage is slight to moderate, considering the impacts on the structure and functioning of the large ecosystems that comprise the coastal zone of Sri Lanka. Some of the damage had been exacerbated by haphazard disposal of debris during relief operations.

Predicting the next Tsunami

Although a great deal is known about where earthquakes are likely to occur, there is currently no reliable way to predict the days or months when an earthquake will occur at any

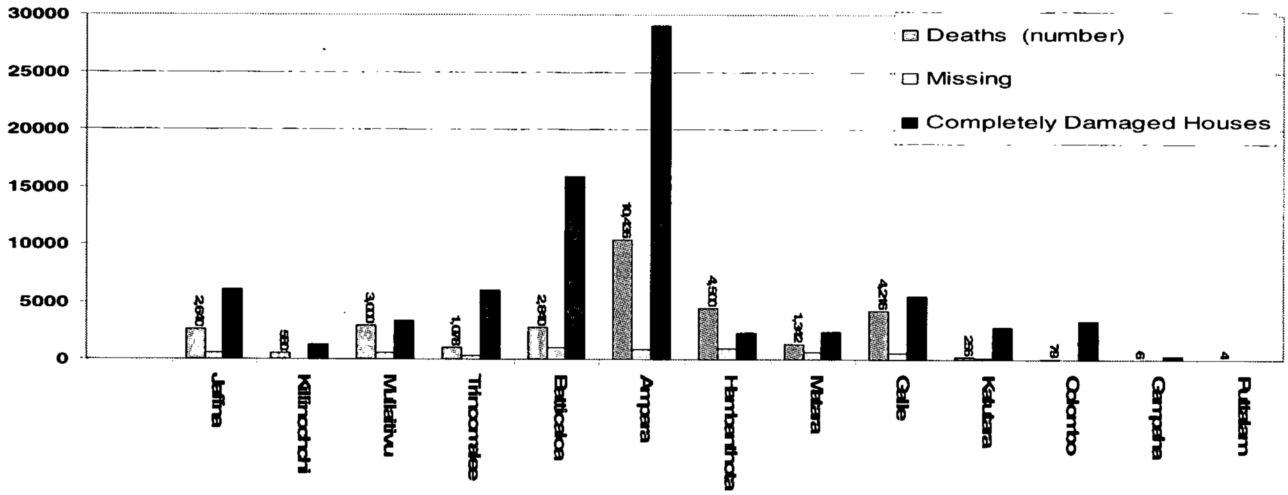


Figure 5: The Human Cost by District

specific location . The United States Geological Survey is thus focusing its research efforts on developing long-range earthquake probability forecasts in seismically active areas. The only on-going USGS research in earthquake prediction is the Parkfield Prediction Experiment, where more than a 100 scientists are studying the possibility of predicting when the next earthquake will occur in this earthquake prone area of California. The present position is that it is not possible to predict when an earthquake would happen at any particular point on the earth. Consequently, it is not possible to predict the time of origin of any tsunami.

We design dams, flood protection schemes and other infrastructure around the world whose safety is determined purely on the probability of occurrence of design storms selected on the analysis of rainfall records. The Colombo Flood Protection Scheme will protect the city from a flood of return period 100 years. On the other hand the spillway on Victoria Dam could pass a 1000 year flood without overflowing the dam and endangering the abutments on which it rests.

There are sufficient historical records of earthquakes available to estimate the probability of occurrence of an earthquake of a given magnitude at a very earthquake prone area such as the Sunda Trench. Thus, after some study it should be possible to assign return periods to the tsunamis generated by the earthquakes of 26 December 2004 and 28 March 2005. It is likely that the return period of the former will be found to be of the order of several centuries. The steps we take to prepare ourselves for the recurrence of such a disaster must necessarily take into account the probabilities of recurrence. We must also take account of the higher probability of occurrence of smaller tsunamis and localised flooding due to cyclones.

Tsunami Preparedness

Once the immediate relief has been delivered and the lives and livelihoods have been stabilised, we need to have a plan for the future.There are several ways of responding to this disaster. The extreme positions are either to abandon all the areas damaged by the last tsunami or to carry on as if this event will never recur. Given the large areas damaged by the tsunami, in some places extending more than a kilometre inland, the act of abandoning such a large area of valuable land on account of something that might not recur for centuries seems foolish. On the other hand, there is always a finite chance that even the unlikeliest event could recur within the foreseeable future. Thus to ignore this danger and the fear that is just below the surface in many people who directly encountered the tsunami and survived, would be to hide our heads in the sand.

All reasonable geologists believe that the Sunda Trench is the only possible source of a tsunami that could bring destruction to Sri Lanka. Other plate boundaries in the Indian Ocean (including the so-called emerging boundaries) cannot undergo the type of subduction that would give rise to a massive vertical displacement of the sea bed. Therefore, we have a lead time of 2 hours from the occurrence of a major earthquake before a tsunami wave can reach the East Coast of Sri Lanka. Even the best available technology at the Pacific Tsunami Warning Centre takes about 30 minutes before they can collate seismic and other data sent from real-time instruments around the globe and determine the strength, location and depth of the earthquake and whether a particular event could generate a destructive tsunami. Thus a tsunami alert could be issued by an Indian Ocean Tsunami Warning Centre (yet to be established) about 1 hour and thirty minutes before the first wave reaches the east coast of Sri Lanka. If we are able to organise a reliable system of disseminating such information quickly, and if the population in every vulnerable locality is trained in advance about how and where to go, it would be possible to minimise the loss of life. There are however areas where there are no safe areas for the population to withdraw to at short notice. It is necessary in these places to build tsunamis shelters high and strong enough to keep the people safe. These shelters could double as public buildings such as schools at other times.

As we have mentioned before, we cannot know at the time of issuing an alert (such as on 28 March 2005) whether a tsunami has been generated and if it has been, whether it would be large or small. The actual arrival of a tsunami wave will be detected soon after the earthquake at locations close to the epicentre, i.e., in Sumatra. Thus Sri Lanka is in a fortunate position of being able to reduce the level of alert or even issue an all clear quite quickly after the event.

Setting up a Warning Centre is the easiest part of the task. There are many countries with a great deal of experience and know-how (eg. the US and Japan) who are willing to help at very little cost to us.The more difficult task is to set up our internal dissemination system and to educate the coastal population on how to respond to a warning issued by the authorities. This would include tsunami warning drills to validate the system.

Geological processes evolve over millions of years.Thus the probabilities of occurrence of tsunamis will not change during our historical period. On the other hand, global climate change is an established fact, and there is every likelihood that climate driven events such as cyclones will become more frequent and more intense within our lifetime. Flooding due to a severe cyclone is therefore a more likely scenario than a repeat tsunami. A cyclone will however cause flooding only in a very limited area, and wind damage is likely to be the worst impact over a larger area. Disaster preparedness should therefore be extended to cover these hazards.

Conclusion

It is grossly unfair to find fault with anyone for not having predicted the tsunami or for not having acted to warn people in time. The truth is that the best informed people did not know that such a disaster could happen. On the other hand, because we now know that such an event is a possibility we will be remiss if we did not act upon that knowledge. However, our response must be measured. Setting up a warning system is relatively inexpensive. If expert analysis reveals that the 26 December tsunami was due to a very rare combination of circumstances unlikely to be repeated within several centuries, we prepared to able to save the human population rather than protecting property. Better design of houses and other infrastructure and better planning for disaster relief could reduce the recovery period from such a tsunami to several months instead of several years. The cost of such a recovery is likely to be far less than the economic cost of abandoning some of the most valuable property the country owns for an indefinite period.

Acknowledgements

Much of what has been written above are the result of the author's direct experience and his interactions with many professionals and scientists who cannot be mentioned individually. Special acknowledgement must however be made of the website of the United States Geological Survey which provided much of the scientific material and graphics presented above. The author was fortunate to be able to draw on his observations of tsunami damage while visiting these areas as a member of the Rapid Green Assessment team of the Ministry of Environment & Natural Resources. Thanks are also due to Drs Jayampathy Samarakoon, Sriyanie Miththapala and Janaki Galappatti for their critical comments. Nevertheless the opinions stated in this paper are only the Author's own.

THE PROPAGATION OF THE KILLER WAVE

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On 26th December 2004, a bright sunny morning free of winds and showers, the Sri Lankan coastline witnessed the devastating impact of a Tsunami, hitherto unknown phenomenon to many Sri Lankans. A Tsunami is one of the many coastal hazards which Mother Nature can unleash. The name Tsunami is after a Japanese word for storm/harbour waves. These are also referred to as tidal waves although they are not related directly to the tides. To a country which has been free from major coastal hazards apart from coastal erosion, occasional overtopping during storm attack and storm surges which are relatively mild, this was a devastating blow unparalleled in its history.

Generation of the Tsunami

Tsunami water waves are generated by underwater earthquakes or volcanoes. This causes the surrounding ocean to bulge and then spread out in a series of waves. The waves spread from the epicenter of the earthquake which causes the seabed to shift. Although Tsunamis are generated by seismic activity, the propagation of the waves and their behaviour is understood via Wave Theories of Ocean and Coastal Engineering very different to that of Geology. The seismic disturbance which generates the Tsunami may occur far away so that shock waves from the seismic event would not be felt on land. This is one of the greatest disadvantages which prevent alertness or disaster preparedness. However if the location and the strength of the earthquake is detected it provides very valuable lead time for the evacuation of people from the coastal zone. Tsunamis have the ability to propagate in deep water at very high speeds without being noticed. If not detected, a Tsunami can strike without warning, often on a very calm and bright day as it happened in Sri Lanka.

Propagation of the Tsunami towards the coastline

As the waves travel through the open ocean waters, they can reach over 200 km in length (between the crest of one wave and the next one). However their height may be limited to comparatively small values of the order of 1.0 m in deepwater. The waves themselves move very fast with speeds of propagation (celerity, c) exceeding 800 km/hour (222 m/sec). Tsunamis can travel over thousands of miles before increasing its height on reaching the shoreline. The periods of Tsunamis are generally in the order of several minutes to an hour. In this process they can pass by ships in deepwater without even being noticed (Figures 1 and 2).

Figure 1: Tsunami Wave

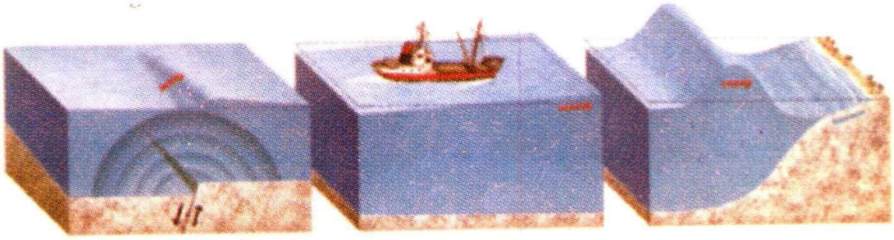


Figure 2: The propagation of the Tsunami Wave (Generation, movement as a relatively low amplitude wave in deep water and the build up near the coastline

The wave height at any point of a propagating Tsunami is related to its distance from the origin, the energy content and area of the initial disturbance, and to energy losses in transit which are generally small except in the immediate locality of the disturbance.

Even in the open ocean the ratio of depth (d) to wave length (L) is such that Tsunami travels as a 'shallow water wave'

$\left(d/L = 1/20\right)$ Speed (c) of such waves are governed by the depth of ocean over which it passes and is estimated by $c = \sqrt{gd}$

On reaching shallow water, the speed reduces but the energy in the wave remains the same due to minimum losses thus increasing the wave height very rapidly and subsequently crashing inland with devastating power and destruction (Figures 1 and 2). The Tsunami strikes in a series of waves whose magnitude can vary. The first wave need not be the largest in the series.

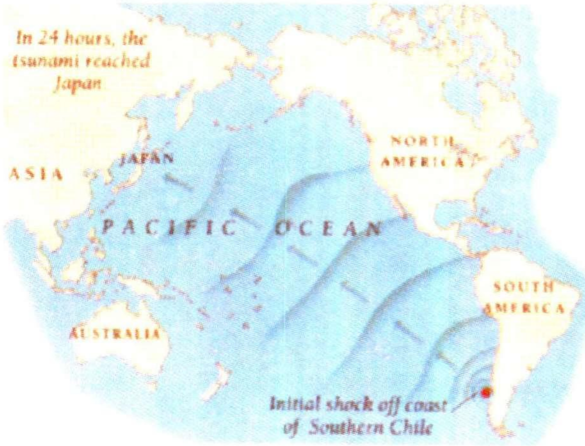
The exposed beach

It is interesting to note that when the Tsunami wave recedes the trough of the wave exposes an unusually long beach in the direction of the ocean. Many people observed this phenomenon which was certainly alien to them. Since Sri Lanka has a small tidal range its people have very little knowledge on exposed beaches which are otherwise observed during low tides. Hence people watched with amazement the receding coastline. However in the context of Tsunamis it is a danger signal indicating that the next wave will be racing towards the shore within a short period. Those who ventured into the ocean to explore the previously unseen seabed were certainly on a path of suicide. The normal waves which people witness and play with on the friendly beaches have periods in the range of 5-16 secs and have comparatively short wavelengths. Tsunamis on the other hand have periods which can reach an hour and their wavelengths can be of the order of several kilometers near the coastline. Hence it is natural that they expose a wide beach, of equal order of length when the trough of the wave is on the beach front. The fast moving crest of the next wave is only a few kilometers behind racing towards the shoreline with unimaginable power and gaining height.

Previous Tsunamis

Periodically the world has witnessed the destruction caused by Tsunamis large and small. Tsunamis have been primarily generated as a result of submarine earthquakes and volcano eruptions. Landslides moving into the oceans and underwater explosions arising from test blasts can also generate tsunamis.

In 1960 a powerful earthquake hit Chile in South America measuring a magnitude M = 8.25 to 8.50 on Richter Scale. The Tsunami progressed rapidly diagonally across the Pacific Ocean, causing massive damage in Japan. Having moved right across the Pacific Ocean it still had power to cause tremendous damage in Hawaii and Japan (Figure 3). A Tsunami can move across the Pacific Ocean within 24 hours. The tsunami which hit Sri Lanka travelled over 1400 km.



Tsunamis are also caused by the eruption of an underwater volcano or a volcanic island. Classic example of such an eruption is that of the island volcano of Krakatau which exploded in the early 1880s. A Tsunami having a height of the order of 35 m is believed to have smashed into the nearby islands of Java and Sumatra killing more than 35,000 people. An adventure movie "Krakatau - East of Java" which was screened in the Majestic Cinema in the seventies was an excellent and educative visual screen experience of what a Tsunami looked like.

Majority of the recorded Tsunami have been in the Pacific Ocean which is suppose to have more than 10,000 volcanoes. Japan is one of the countries which have been at the receiving end of Tsunamis generated from near and far. Coastal Engineering researchers from Japan have made a significant contribution in understanding the initial disturbance, propagation and the final blow on land of Tsunamis.

Correlating the strengths of the Earthquake and the Tsunamis

On account of their relative infrequency of occurrence and unpredictability much remains to be understood of the hydraulics of Tsunamis. The behaviour of Tsunamis presented in the article are primarily based on Japanese research studies covering Geology and Coastal Engineering. Although the propagation of waves into shallow regions could be modeled it is not an easy task of estimating the wave height at the centre of the seismic disturbance. It is equally difficult to correlate the strengths of the earthquake and the Tsunami.

Professor Kiyoshi Horikawa, the renowned Coastal Engineering academic from Japan has compiled and presented information from many research sources in Japan. In areas subject to Tsunamis statistical data on their frequency, magnitude and impact have been collected and analyzed leading to graphical and empirical relationships among key parameters. These quantitative relationships have to be applied appreciating fully their limitations in particular on the characteristics and quality of data which have been used.

It is equally important to recognize the local features and nearshore processes such as diffraction and refraction which would also influence the degree of the final impacts at a given location. Even on the southwest coast certain locations were very seriously affected while other escaped with little damage. Although the relationships, to be discussed below, may not be strictly applicable to Sri Lanka it certainly provides the "scientific thinking" behind the quantification process and the directions on which the subject has advanced.

In the case of Tsunamis generated by submarine earthquakes, there has been a continuous demand to relate the strengths of the Tsunami and the earthquake. The magnitude of an earthquake "M" is defined by the well known Richter Scale. The strength of the Tsunami cannot be easily defined. Several classifications have been presented by researchers. Table 1 illustrates the classification of the strength of the Tsunami expressed as a magnitude "m" after Imamura. Iida introduced a linear correlation between m and M based on available statistical data, leading to

$$m = 2.61\ M - 18.44 \text{ -------Eq.1}$$

Therefore an earthquake of the order of $M < 6.5$ may not generate any notable Tsunami. On the other hand if $M = 9$, the Tsunami magnitude is greater than 5 leading to severe damage. It has been recognized that if the epicenter of the earthquake is shallow the magnitude of the Tsunami generated is greater.

It is recognized that the type of displacement arising from an earthquake is also important in its contribution to the formation of the Tsunami. Vertical displacement of the seafloor is of primary importance for the generation of Tsunamis. Usually the strike- slip motion free of vertical displacement is not a great threat.

Several researchers have also quantified the total energy of the seismic motion, Es, and the Tsunami energy, Et. These are linear relationships in terms of m and M. The Tsunami energy is estimated to be about 10% of the earthquake energy.

Iida also established a relationship between the fault length l (km) and the strength of the earthquake, M. The fault length indicates the size of the region where the Tsunami is generated.

$$M = 6.27 + 0.63 \log l \text{ -----------------Eq.2}$$

The above expression indicates that for an earthquake greater than 8 on the Richter Scale is associated with a fault line exceeding 1000km. This was the order of the fault line of the earthquake of 26th December.

Hattori used mathematical modeling to study the areas of Tsunami origin and established the shape of such regions is approximately an ellipse. This was based on historical information on earthquakes as well as recent Tsunamis. He determined the long and short axes 'a' and 'b' of the aftershock and related to the strength of the earthquake. This is a very important parameter because it represents the direct linkage between the fault length and the area of the ocean surface which becomes the source of the tsunami. It is argued that the orientation of the main axis of that ellipse plays a vital role in the direction of propagation of the Tsunami. This is also useful in detecting the overall extent of potential coastline subject to the Tsunami impact (Figure 4). It seems that the fault line and the resulting major axis of the 'Tsunami source ellipse' were more or less parallel to the north south axis of Sri Lanka thus causing major damage. For example in the Chilean Tsunami of 1960 (Figure 3) the orientation of the Tsunami source was such that Japan and Hawaii was at the receiving end while Australia was lucky to escape.

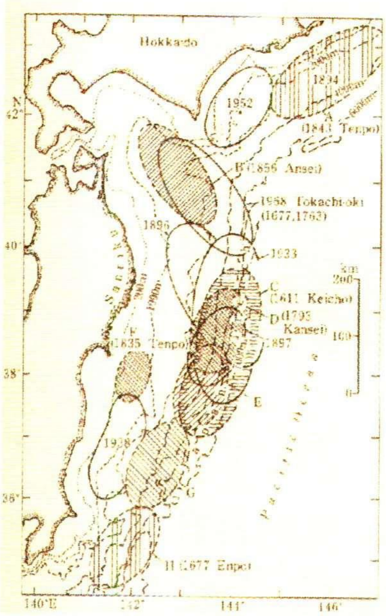


Fig. 4: Tsunamis closer to the Japan

Takashi also related the predominant period of the Tsunami Te (min) to the strength of the earthquake leading to

$$\log Te = 0.57\, M - 2.85 \text{ ----------Eq.3}$$

Unlike Japan it is most unlikely that Tsunamis which affect Sri Lanka will be generated by earthquakes very close to Sri Lanka. In this context what would be relevant is to obtain information of earthquakes such as the one which took place on the 26th and previously in that region to correlate the impact of the Tsunami and the earthquake giving due consideration the distance between the source of origin and the coastline. This will at least enable to make predictions, however approximate it may be, once early information of the earthquake is known.

The fact that locations of possible submarine earthquake are at a great distance from Sri Lanka has the advantage of the country possessing a very valuable lead time.

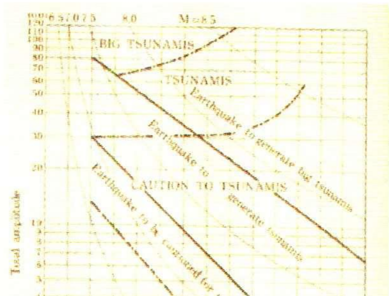


Fig. 5: Tsunami Curves

The prediction of the wider impacts of a Tsunami based on the strength of the earthquake is difficult. Figure 5 illustrates a diagram for estimating the magnitude of Tsunamis generated by nearby epicenter earthquakes, revised by the Metrological Agency of Japan. This diagram clearly illustrates the influence of the strength of the earthquake as M increases from 7.0 to 8.5

Planning and Implementation of Countermeasures

Sri Lanka has now witnessed the devastation of a Tsunami and it is in the national interest to identify Countermeasures in the Short Term and in the Long Term. This is considered necessary even though it is most unlikely that an extreme event of this nature would occur for years to come.

In planning for countermeasures high priority should be given to

(i) Obtaining information at the very earliest of submarine earthquakes or similar phenomena occurring closer to the shoreline of our neighbouring and extended neighbouring countries across the oceans.

(ii) To constitute at the earliest a Tsunami Monitoring and Prediction Committee, comprising relevant officers from state agencies and professional who could contribute to the prediction and monitoring process and advice on countermeasures. The said Committee should undertake the following activities on a priority basis.

(iii) Review the extensive information now available, in particular via the visual media to assess the characteristics of the wave and flooding which struck different parts of the country on the 26th December. They contain wealth of information on vulnerability, damage and drainage. It is equally important to review the events which took place in neighbouring countries. Such a procedure will enable to prepare an extensive data base which will help in planning countermeasures and also be very useful for future urban and town planning.

(iv) Institute a mechanism by which to receive information of earthquakes at the very earliest and thereby predict, however approximate it may be, a conservative estimate of the lead time and also establish an effective warning system.

(v) Formulate the organization of a speedy evacuation system and the establishment of refuge areas. This may require evacuation training to understand the problems and issues relating to such a process.

(vi) Formulate an effective public awareness programme to educate the people living in the coastal areas. This should give high priority to provide a clear explanation of the phenomenon in simple terms, precautionary measures and on the need to avoid speculation leading to panic which is gradually taking root is society in the absence of educative awareness programmes.

In the long term the authorities will have to redefine policies on urban and town development in the coastal zone. This may require large scale relocation of houses from low lying to safe areas. The planning of coast protection measures have to be reviewed and it may become necessary to construct in the long term storm surge breakwaters at very vulnerable areas.

On the 26th December 2004, Sri Lanka had at least 2 hours of lead time to respond to the pending devastation. On this occasion they failed to capitalize on the critical lead time. This led to the large scale loss of lives, property and vehicles. By adopting well formulated procedures and making use of the lead time it is certainly possible to minimize the loss lives and vehicles by moving a distance as short as 2km inland.

Tsunami Magnitude *m*	Tsunami height *H*	Damage
-1	50cm	None
0	1m	Very small damage
1	2	Coastal and ship damage
2	4 ~ 6	Damage and lives lost in certain land-ward areas
3	10~20	Considerable damage along more than 400km of coastline
4	30	Considerable damage along more than 500km of coastline

Table 1 : Tsunami Classification (after Imamura)

THEIR CAUSES AND EFFECTS

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Introduction

On 26th of December 2005, Sri Lanka experienced, perhaps its most devastating natural disaster through an impact of a Tsunami. The Tsunami, a Japanese word meaning 'harbour wave', was the result of an earthquake off the coast of Sumatra with a magnitude of 9.0 on the Richter Scale and caused widespread damage in the region: both to property and human lives with over 300,000 deaths and millions made homeless. In this paper, the causes and mechanisms of tsunami generation, theory of wave propagation are reviewed and the impacts of the 2004 Indian Ocean tsunami globally and in particular in Sri Lanka are presented.

Generation and Propogation

Tsunamis have been referred to as "tidal waves" by the media and the general public and as "seismic sea waves" by the scientific community. However, the term "tidal wave" is incorrect as tidal waves are generated through the gravitational effects of the sun and moon. Although the impact of a tsunami on a particular coastline depends on the local water level at the time of tsunami impact, tsunamis are unrelated to the tides. The term "seismic wave" is also misleading as they generally relate to the acoustic waves generated from an earthquake traveling through the Earth's crust.

A tsunami is a wave train consisting of a series of waves, of long wave length (> 100 km) and period (order of hours), generated in a body of water by an impulsive disturbance that vertically displaces the water. Tsunamis are primarily associated with earthquakes in oceanic and coastal regions. Landslides, volcanic eruptions, nuclear explosions, and even impacts of objects from outer space (such as meteorites, asteroids, and comets) can also generate tsunamis. The most common type of tsunamis is those associated with tectonic earthquakes, associated with the earth's crustal deformation. An earthquake which produces a tsunami is known as a tsunamigenic earthquake. When a tsunamigenic earthquake occurs beneath the sea, the water above the deformed area is displaced from its equilibrium position. Waves are formed as the displaced water mass, which acts under the influence of gravity, attempts to regain its equilibrium. This displacement of the sea surface initiates a series of waves radiating outwards from the initial disturbance similar to that observed when a pebble is dropped onto a pond. When large areas of the sea floor elevate or subside, a tsunami can be created. The main factor that determines the initial size of a tsunami is the degree of vertical sea floor deformation which is controlled by the earthquake's magnitude, focal depth (the depth below sea bed at which the earthquake occurs), fault characteristics and coincident slumping of sediments or secondary faulting. Generally, for a tsunami to be generated the earthquake should have a magnitude > 6.5 on the Richter Scale and also the earthquake needs to be relatively shallow, between 20 and 100 km below the seafloor. A shallower depth provides the strongest "impulse", but a deeper earthquake distributes the "impulse" over a larger area (Okal, 1988).

As the tsunami crosses the deep ocean, its wave length from crest to crest may be several hundred kilometers or more, and its height from crest to trough will only be < 1m. They can not be felt aboard ships nor can they be seen from the air in the open ocean. The celerity (speed) of the tsunami is given by $C = \sqrt{gH}$ where g is acceleration due to gravity and H is the total water depth. Thus, as the water depth decreases, the speed of the tsunami also diminishes. In the deepest oceans, the waves will reach speeds exceeding 10 ms-1 (> 900 km hr-1). i.e similar to that of a jet aircraft. The energy flux of the tsunami, which is dependent on its wave celerity and wave height, remains nearly constant. Therefore, as speed of the tsunami decreases, as it enters shallower water, the height of the wave grows. Because of this "shoaling" effect, a tsunami that was imperceptible in deep water may grow to be several meters or more in height.

When a tsunami finally reaches the shore, it may appear as a rapidly rising or falling tide, a series of breaking waves, or even a bore. The waves often persist for 3-5 days decreasing in amplitude with time. Generally, the highest water level is not reached during the first wave but rather the second or third wave. Reefs, bays, river mouths, undersea features and the slope of the beach all help to modify the tsunami as it approach the shore. Tsunamis rarely become great, towering breaking waves. Sometimes the tsunami may break far offshore. Or it may form into a bore: a step-like wave with a steep breaking front. A bore can result if the tsunami moves from deep water into a shallow bay or river. As the effect of the tsunami on the shoreline is controlled by the local bathymetry, a coastal area may see no damaging wave activity while in another area, within several kilometers can experience destructive waves. The coastal flooding of a region can extend inland by several kilometers or more, covering large expanses of land with water and debris. Tsunamis may reach a maximum vertical height onshore above sea level, called a run up height, of 30 meters. A notable exception is the landslide generated tsunami in Lituya Bay, Alaska in 1958 which produced a 525 meter run-up.

Since science cannot predict when earthquakes will occur, we cannot determine exactly when a tsunami will be generated. But, with the aid of historical records of tsunamis and numerical models, science can get an idea as to where they are most likely to be generated. Past tsunami height measurements and computer modeling help to forecast future tsunami impact and flooding limits at specific coastal areas. There is an average of two destructive tsunamis per year in the Pacific basin. Pacific wide tsunamis are a rare phenomenon, occurring every 10 - 12 years on the average.

In the Indian Ocean, the Indo-Australian plate is sub-ducted beneath the Eurasian plate. This is the region known as Sunda Arc, located to the south of Indonesia. In total, < 6% of all tsunami activity in the Indo-Pacific region occurs in this region. Along Sumatra, large tsunamis have been recorded 3 times in the past 200 years. There have been 19 earthquakes of magnitude 7 and higher that have occurred in this region since 1900 (Pattiaratchi and Woo, 2000).

The only previous documented impact of a tsunami was in 1883 through The Krakatoa eruption. This caused a 35m wave in Indonesia. The resulting tsunami has been reported in newspaper articles in Sri Lanka with impacts reported from Galle, Negombo and Arugam Bay where there was one casualty. The maximum wave height was reported to be 1m and the tsunami impacted Sri Lanka 5-7 hours after the eruption.

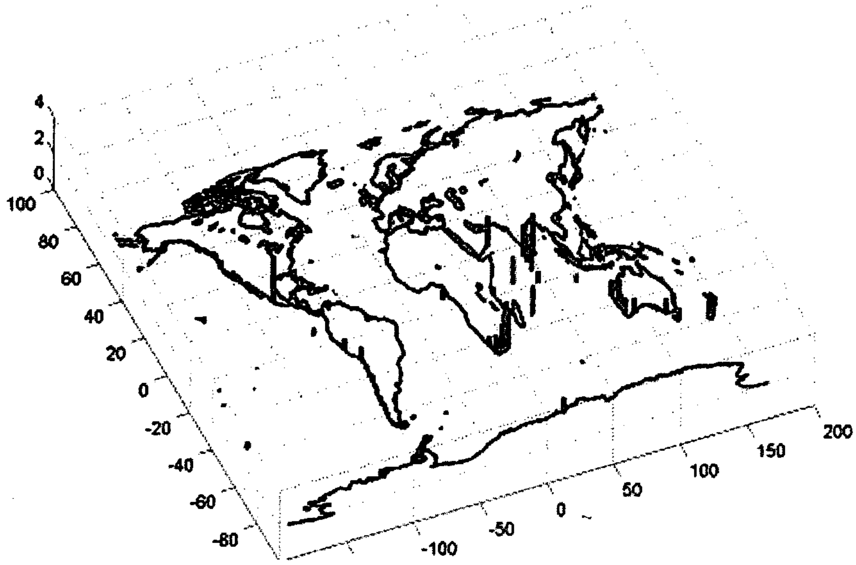

Figure 1 - Global distribution of tsunami impact as recorded by coastal tide gages.

The 2004 Sumatra Earthquake and Tsunami

The earthquake which caused the tsunami was located off the west coast of northern Sumatra (16°N, 95.854°E) and occurred on Sunday, December 26, 2004 at 00:58:53 UTC (07:58:53 local time) with a focal depth of 30 km. The earthquake was the result of interactions between the Indian, Burmese, Australian and Sunda tectonic plates. It is postulated that a 1000 km of the sea bed was affected due to the Earthquake. The earthquake resulted in the upward movement of the sea floor (max 10m) which disturbed the sea surface and a tsunami was generated. These waves then propagated across the Indian Ocean resulting severe damage to many countries. The tsunami waves were recorded widely across the globe with tidal stations in countries bordering the Pacific and Atlantic oceans as well as those in the Indian Ocean and Antarctica recording water level changes induced by the tsunami (Figure 1).

Table 1 -
Maximum run-up heights from the regions most affected by the tsunami (from http:// www.drs.dpri.kyoto-u.ac.jp/)

Location	Max. Run-up Height
India (Chennai Port)	4.1 m
Maldives (Fanadhoo)	4.65 m
Sri Lanka (Kahawa)	10.04 m
Sri Lanka (Hambantota)	10.61 m
Indonesia (Banda Aceh)	34.9 m

The Impact of 2004 Indian Ocean Tsunami on Sri Lanka

Sri Lanka is located off the southern tip of India. The island has a length of 445km; width of 225km; a total area of 65610km 2 and a coastline of 1760 km. It has a population of 19.6 million of which 4.85 million people live within 1km of the coast which makes up only 4% of the land mass (source: Urban Development Authority). Sri Lanka has a very narrow continental shelf with the mean distance between the coast to the 200m depth contour being 20km - at some locations, especially along the southern coast, this distance is reduced to < 5km. The narrow continental shelf means that Sri Lanka is extremely vulnerable to the action of tsunamis as the shoaling effect occurs over a shorter distance and there is a negligible amount of energy dissipated over the continental shelf region. Sri Lanka is located approximately 1550km from the epicenter of Earthquake. The tsunami waves were recorded to first impact along the eastern coast at ~0855 local time and then propagated along the southern and the northern coasts reaching Colombo at ~1000 and Jaffna at ~1020. Sri Lanka was severely affected by the tsunami with over 1000 km of the coast - from Jaffna in the north to Negombo along the western coast experiencing coastal inundation resulting in loss of lives and property damage. It has been recorded that a total of 30983 people have lost their lives, another 4924 missing, 23248 injured and 596374 people rendered homeless.

Sea level data, at two minute intervals, were collected from the tide gage located in Mutwal fishery harbour, Colombo. The data clearly shows the influence of the tsunami (Figure 2). The maximum water reached 2.65m over a time period of 10 minutes. Subsequent to the initial packet of waves, enhanced high frequency oscillations were present for 4 days superimposed on the tidal record (Figure 2). Spectral analysis of 5 days of data obtained before and immediately after the tsunami indicated that the high frequency energy (e.g. at 75mins) was enhanced after the action of the tsunami (Figure 3). Although the tide gage was located within a harbour, the 75min oscillation relates to the first mode of the oscillation of the entire continental shelf of the study region: here, the continental shelf has a mean depth of 50m and a width (to the 200m contour) of 8km. Hence, in this case, the tsunami enhanced the existing natural oscillation of the entire continental shelf.

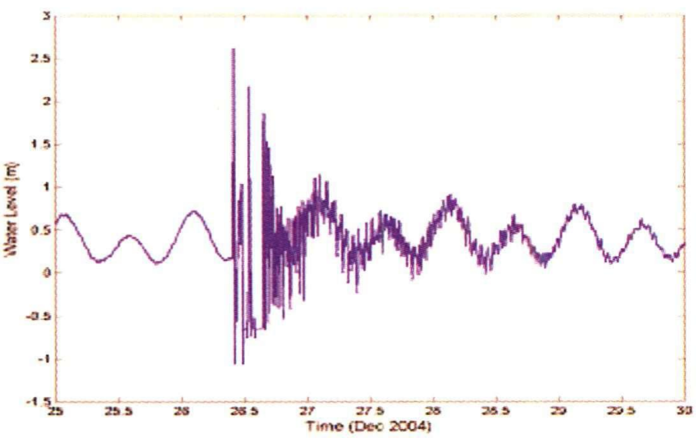

Figure 2- Time series of water level at Mutwal Harbour showing the initial waves and enhanced seiching after the initial wave incidence.

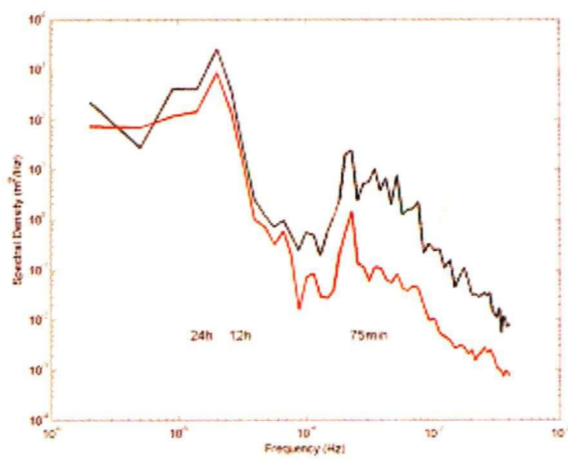

Figure 3 - Water level spectra from Mutwal Harbour showing the spectral energy before and after the action of the tsunami.

Run-up Distribution around Sri Lanka.

Run-up data, i.e. the maximum height of the water level, collated from different sources, including those obtained from internet resources (http://www.drs.dpri.kyoto-u.ac.jp), Dr E.M.S. Wijeratne of NARA and the author are shown on Figure 4. The maximum heights of over 10 m were recorded at Hambantota and Kahawa (location of the train disaster) and 11 m at Kalmunai. Other selected locations where measurements are available include Nilaveli (5.1m), Kirinda (9.1m), Tangalle (3.7m), Dickwella (4.9m), Matara (5.8m), Koggala (9.3m), Galle (4.9m), Payagala (6m), Panadura (5.6m) and Colombo (2.7m).

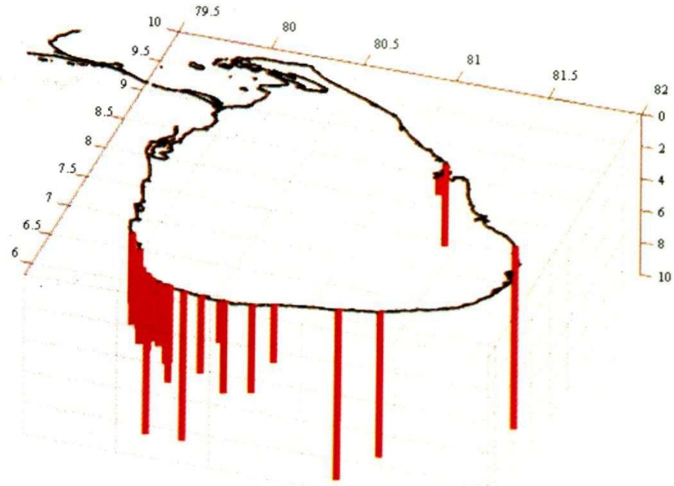

Figure 4 - Run-up heights reported from locations around Sri Lanka.

Acknowledgments

The author would like to thank Dr E.M.S. Wijeratne of the National Aquatic Resources Research and Development Agency (NARA, Colombo) for providing the sea level data from Mutwall harbour and the internet resources available from the following sites from which Figures 1 and 4 were constructed: http://www-sci.pac.dfo-mpo.gc.ca/ and http://www.drs.dpri.kyoto-u.ac.jp/, respectively. This is Centre for Water Research, The University of Western Australia reference ED 2067 CP.

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IMPACT OF TSUNAMI ON COASTAL FISHERIES, THE REHABILITATION ACTIVITIES REQUIRED AND THE RESEARCH NEEDS

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Fisheries sector of Sri Lanka is of considerable social and economic importance to the country. Fish contribute about 65% of the animal protein consumed by the population of the country. This is largely contributed by the coastal and off-shore fishing industry which produced 284,960 tons of fish in 2003 and was responsible for providing 83% of the total quantity of fish consumed in the country. Before tsunami, it provided direct employment to about 250,000 persons and around 1 million people in fishing households dependent on the sector. In 2003, the industry contributed 2.6% to the GDP of Sri Lanka. In the recent past, the fishing industry has also emerged as a dynamic export oriented sector earning substantial amount of foreign exchange. In 2003, foreign exchange earned through exports of fish and marine products amounted to Rs. 9.5 billion (Streaminitiative 2005)

Marine fish catch is landed at 12 fishery harbours and many other landing sites.

In 2003 the fishing fleet in the country was comprised of 29,694 fishing crafts of various types. The most important types are,

- **Multi-day boats** (ranging from 34-50 ft in length), powered by inboard engines, manned by 4-5 fishers and having crew accommodation, with built-in insulated fish holds and facilities to carrying large quantities of water and fuel, and making fishing trips lasting for 7 to 20 days.

- **3½ ton boats** powered by inboard engines, manned by 3-4 fishers. These boats normally carry out single day fishing activities.

- **Fibreglass Reinforced Plastic (FRP) boats** 18-23 ft long, powered by outboard engines manned by 2-3 fishers and confined to day fishing.

- **Traditional crafts**. These comprise:

  1) **dug outs** "Oru" outrigger canoes on the southern and western coasts, or "thoni" or "vallam" largely on the northern and eastern coasts. Some of these are powered by outboard engines but the bulk of these are non-motorized. Initially these were dug out from logs but these craft are now turned out of fiberglass; and

  2) **log craft** such as "teppam" (mainly on the north west coast) or "kattumaram" on the northern coasts.

Marine fisheries also support a series of fishery associated industries and activities ranging from the manufacture of boats, nets and gear, fish processing, transport and marketing, production of ice, curing/drying of fish etc.

Total damage to fisheries sector due to tsunami

Total direct damage to the sector is estimated at Rs.12000 million. According to the revised estimates of the Ministry as at 03.02.2005 the details of boats destroyed and damaged are as follows (Streaminitiative 2005)

Damage to vessels

Total Number of boats-Pre-tsunami (in 2003)	29694
Total Number of boats-Damaged and totally destroyed	15578

Number of different types of boats damaged and destroyed

Number of Multiday Boats	593
Number of 3½ ton Boats	953
17-23' FRP boats	5652
Traditional crafts	8380

Fishing gear and engines damaged or totally destroyed

Beach seine	721
Other gear	10994
Out board motors	2687

Human cost

Number of dead fishermen	7705
Number of missing fishermen	2571
Number of displaced fishermen	66281
Number of houses destroyed	32989

Fishery Harbours

Ten out of the 12 fishing harbours have been impacted to varying degrees. Damage has been estimated to be Rs.1333 million.

Ice plants, Cold storages

In the south, five ice plants are badly damaged and required major repairs to civil works including insulation as well as refrigeration equipment. The cost of relacement/ repairs is yet to be estimated.

Estimates of financial damage to other facilities in the fisheries sector (Streaminitiative 2005)

CEYNOR foundation:	Repair and replacement of boats, provision of nets as replacement for damage, office equipment, chemical etc. at Mattakkuliya, Beruwala, Galle, Tangalle and Kirinda: Rs. 6.6 million
National Aquatic Resources - and Research Agency (NARA)	Repairs to damage buildings and equipment, fisheries museum, laboratories, auditorium and stores tec. (excluding damages to Hydrographic Survey boats): Rs 385 million

Coast protection and conservative division:	Loaders etc.: Rs 110 million
National Institute of Fisheries & Nautical Engineering:	Repairs to buildings and training boats and demonstration equipment: Rs 85 million
Ceylon Fisheries Corporation:	Repairs to ice plants, cool rooms, freezer containers and various equipment etc: Rs 63 million
Monitoring Control and Surveillance System:	Repairs to buildings, replacement or repairs to equipment and radio communication system and replacement for the surveillance boat: Rs 63 million
Total	Rs 649 million

Recovery needs and government assistance programmes

Immediate priorities that have been identified by the Ministry of Fisheries and aquatic resources (MFAR) are as follows:

- Repair of boats and engines
- Provision of fishing gear, and
- Clearing of harbours and clearing debris/ other matter on the beaches that obstruct the landing/parking of FRP boats and traditional crafts.

The medium-long term priorities identified by the MFAR include the following:

- Determination of the types and numbers of boats to be replaced taking due cognizance of the resources/carrying capacities etc.
- Replacement of damaged boats with better designs, taking into consideration the need to reduce post-harvest losses and fuel efficiency
- Introducing offshore fishing and new techniques to areas lacking in these fishing methods/ techniques
- Improving/rehabilitating the infrastructure particularly the harbours and anchorages, ice plants and cold rooms and connected vehicles, workshops and slipways etc, and
- Improving the community/social infrastructure including fishery feeder roads, auction halls, fishers rest rooms, community centers, beacon/guiding lights near boats landing centers and water and sanitation facilities.

Restructuring research on fisheries and aquatic resources

Most fisheries scientists are of the view that the research activities on fisheries have to be reorganized.

It is necessary to use modern techniques such as GIS for oceanographic studies and management of marine fisheries and aquaculture.

The potential yield and optimum fishing effort for coastal waters should be estimated and the optimum number of boats that to used in coastal fisheries should be estimated. If there is excess labour, it should be used in off shore and deep sea fisheries.

The involvement of the community in decision-making (co-management) is also necessary to minimize conflicts and for effective management.

Biological parameters in coastal waters should be monitored to predict the potential catch. This can be done using remote-sensing techniques.

A few (3-4) multidisciplinary research projects should be carried out instead of a large number of small research projects which are not related to each other.

The research agenda of the National Aquatic Resources Research and Development Agency as well as other institutes which conduct research in the field of fisheries should be compatible with national fisheries development plan.

It is also of utmost importance to resolve conflicts among different authorities, specially among those dealing with fisheries, biodiversities conservation and urban development.

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RESTORATION AND IMPROVEMENT OF COASTAL ENVIRONMENTS DEVASTATED BY THE TSUNAMI

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Commissioner General of Tsunami Rehabilitation

Introduction

Sri Lanka is endowed with 1,585 kilometers of coastline of sandy beaches, dunes, extensive lagoons and estuaries, mangroves, coastal marshes and sea-grass beds. Coast Conservation Department reports these highly productive ecosystems mangroves, salt marshes, dunes, beaches (including spits) and lagoons (including estuaries) cover an area of 12,189, 23,819, 7,606, 11,800, and 158,017 hectares respectively and bears rich bio diversity. The capital city of Colombo, several municipal councils and urban councils lies within this coastal belt. Further, 62% of major industries and 70% of the tourist hotels are also located. Marine and coastal fishery accounts for 88% of the country's fish requirement and two thirds of the animal protein consumed by the people, whereas coastal fishery itself constitute 68% of total marine fish production. Coral and sand reefs located along the coastal belt are not only biologically productive shallow ecosystems, but also function as natural breakwaters.

The Tsunami

The Tsunami sea surge on 26th December 2004 caused unprecedented devastation on the entire Eastern and Southern coast as well as some parts of Western coast of Sri Lanka. Maximum height of the Tsunami waves around Sri Lanka is recorded as high as eleven meters in South Eastern parts of the coastal belt. Waves have traveled close to three kilometers inland in some locations. The devastation is yet to be assessed, as first priority of the country was for rescue and relief operations. Total number of deaths reported is 30957, with 5637 reported missing.

The Western and Southern coastal belt is well developed while Eastern coast is comparatively densely populated. Population in the costal belt is more than 4.5 million which is 27% of the total population. Tsunami devastation caused one million people displaced of which 500,000 people remained in camps or temporary shelter and around 200,000 housing units damaged of which fifty percent are beyond repairs.

Damage to Coastal Environment

The coastal environment consists of highly fragile eco-systems extending from coastal lagoons and estuaries inland to sand dunes to coral and sand reefs in the continental shelf. Devastation caused to this coastal environment is huge and unimaginable. In certain locations sand dunes are removed to one meter depth either uprooting the beach vegetation or exposing the root systems. Coral reefs, Sandstone reefs and Rocky reefs are spectacular marine habitats supporting biodiversity and now being deposited over by toxic sludge. The percentage of living corals ranges from 5-50 % before the devastation and any further threat to the coral reefs combined with present rate of mining may extinct the life of these spectacular but fragile eco-systems. Deposits of debris, organic materials including dead bodies and toxic sludge swept into the lagoons and estuaries may also have a significant effect on mangroves and other habitats. Devastation caused and its long term effects are not yet known and require a detailed study and assessment. However, appropriate action is not taken immediately, to enhance the natural process of regeneration, some of these systems will be lost for ever. The present exposure of the beaches to natural forces and human interventions is highly disastrous in the long run.

A SCENERY FROM NORTH EAST

DEBRIS ON THE BEACHES

Rehabilitation Programme

The Tsunami devastation is beyond the control of the people and the Government of Sri Lanka. Nevertheless, appropriate precautionary measures could minimize the damage and make people prepare to face a similar disaster in the future. A Presidential decree has already been issued to identify and declare a no-build zone with a minimum width of land (100 meters from the High Water Line on Southern and Western coast and 200 meters on Northern and

Eastern coast). Therefore, the proposed programme will implement the presidential decree and move the human resettlements away from the no-build zone of the coastal belt. However the benefits of the project to the settlers is masked by high population along the coastal belt who are engaged in fisheries industry and other sea related activities and the use of coast as a renewable natural resource, hence resistance from them is envisaged at all times. The programme is planned to be implemented in two stages with the following objectives

a. Implement the presidential decree by the Government, within a reasonable time frame in two phases.

b. Restoration and/or improvement of the coastal environment devastated by the Tsunami.

Location, Area and Activities

The programme will cover the entire coastal belt of Sri Lanka, the total length of which is estimated at 1,585 km. In view of the urgency, under the first phase, around 725 km from seven worst affected districts will be taken up for demarcation, restoration and improvement (Annexure 1A).

The first phase of the project will include following activities

1. Demarcation of the 100 meter (200 meters in North and East provinces), boundary along 725 km coastal belt and planting benchmarks by the Survey Department.
2. Planting special landmarks by the Urban Development Authority using its vested powers.
3. Re-checking the landmarks and preparation of Survey diagrams by the Survey Department.
4. Consultations with the Authorities responsible for rebuilding and relocation activities.
5. Compilation of a data base on unaffected buildings, structures and other development activities within no-built zone.
6. Repairs to coastal conservation structures including breakwaters, bolder barriers and groins.
7. Essential and urgent clearing of debris from lagoons, estuaries, and coral reefs.
8. Detail assessment and identification of needs and issues to formulate a project proposal for restoration and improvement of the coastal eco-systems with donor funding.

The phase two of the project will depend on item 8 above. Tentatively, it will embrace following activities among others.

1. Research and education on suitable vegetation covers and methodology for mass propagation.
2. Establishment of suitable vegetation in damaged sections of beaches, sand dunes, mangroves and marshes.
3. Research and education on methodology for minimizing sand mining in the coastal belt and rivers for the construction industry.
4. Action to be taken for expediting the reformation of the damaged sand dunes.
5. Clearing of debris and other harmful substances from coral reefs, lagoons and estuaries.
6. Undertaking any structural measures require for protection of the Coastal Belt and to arrest coastal erosion.

Implementation, Monitoring and Evaluation Mechanism

The project will be implemented by the Ministry of Public Security, Law and Order while the Survey Department, Urban Development Authority, Coast Conservation Department, Forest Department, Sri Lanka Tourist Board and the Central Environmental Authority will be the supporting agencies at grass root level. Participation of NGOO and CBOO will also be ensured through committees established at National, District and grass root levels. National Steering committee and its composition is given in annexure 1B.

Output and Sustainability

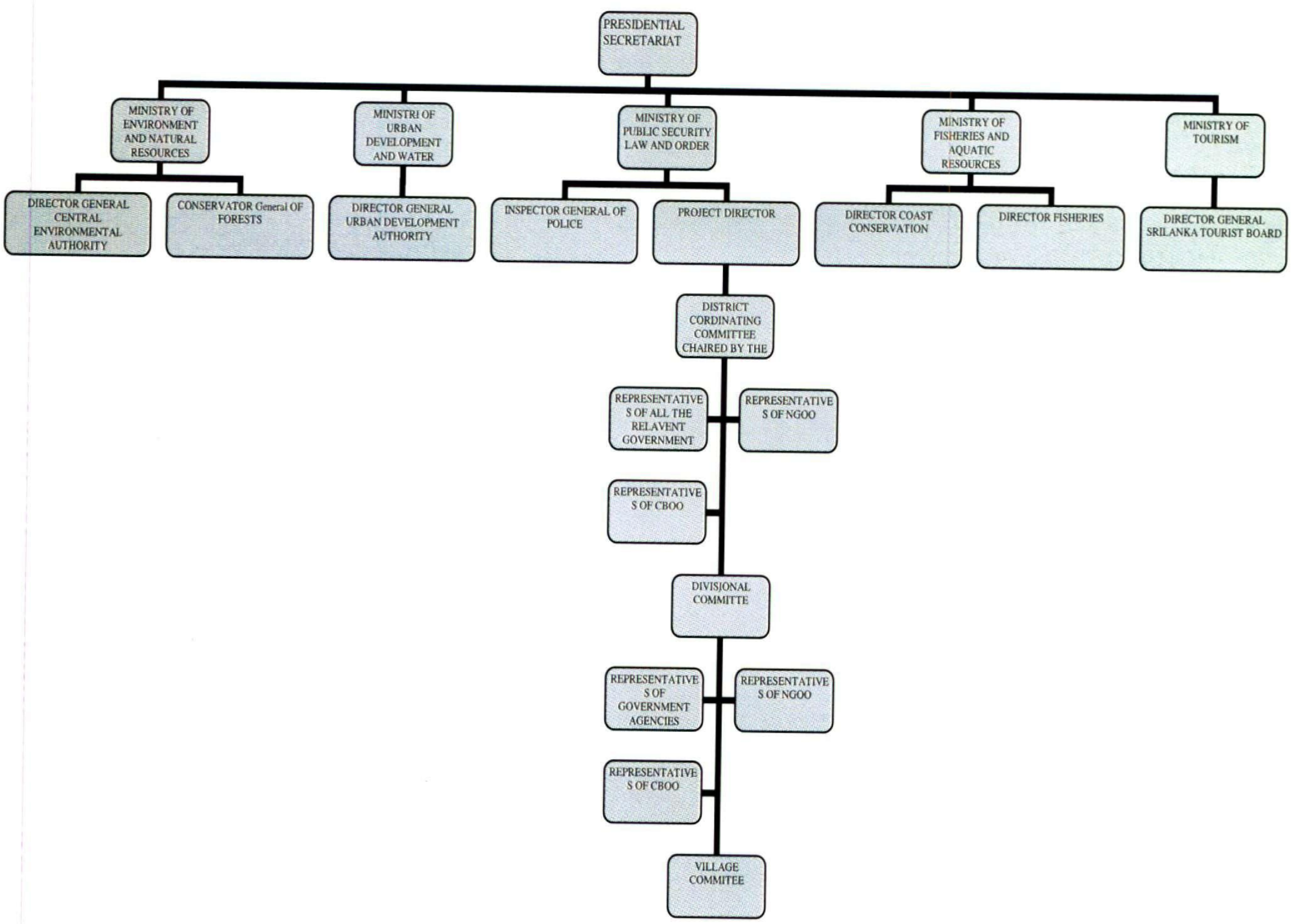
The project is designed to deliver outputs which are directly related to sustainable use of the coastal natural resources. The outputs of the first phase will be:

1. Around 725 km (40%) of coastal belt with properly marked with 100 / 200 meter no-build zone with visible and conspicuous landmarks at 30 meter intervals.
2. Database of all unaffected developments, buildings and structures within the no-built zone.
3. Properly planted and established vegetation cover along the coastal belt.
4. Cleaned lagoon, estuaries, coral reefs and sea grass beds.

These outputs are not only sustainable but facilitate better and efficient management. Coast Conservation Department and the Urban Development Authority shall protect and conserve the no-build zone through the Local Authorities.

Project Organization and Human Resources

First phase of the Project is to be completed within a reasonable time limit, will not have facilities for a project office. The project will be implemented by an unit at the Ministry of Public Security, Law and Order with necessary assistance from the relevant Government and Non Government Agencies.



Annexure I A

A 750km coastal belt was selected as follows based on gravity of the damage and urgency of repair.

1.	Kalutara District	32 km
2.	Galle District	77 km
3.	Matara District	51 km
4.	Hambantota District	150 km
5.	Ampara District	105 km
6.	Baticaloa District	120 km
7.	Trincomalee District	190 km

Annexure I B

At the National level a Steering Committee will be established under the chairmanship of the Secretary Ministry of Public Security and Law and Order. Members of the Steering Committee shall comprise of

1. Secretary, Ministry of Public Security, Law and Order (Chairman)
2. Secretary, Ministry of Agriculture, Land, Irrigation and Livestock Development
3. Secretary, Ministry of Fisheries and Aquatic Resources.
4. Secretary, Ministry of Urban Development and Water Supply
5. Secretary, Ministry of Environment and Natural Resources
6. Secretary, Ministry of Tourism
7. Inspector General of Police
8. Surveyor General
9. Chairman, Urban Development Authority
10. Director Coast Conservation
11. Chairman, Tourist Board
12. Director General, Central Environment Authority.
13. Conservator General of Forest
14. Project Director

Project Director will function as the Secretary to the Committee. The above members may be represented by senior staff if the Secretary of the relevant ministry wishes to do so due to their workload.

POSSIBLE IMPACTS OF TSUNAMI AND AFTER TSUNAMI ACTIVITIES ON COASTAL ECOSYSTEMS OF SRI LANKA

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Sensitive ecosystems in the Eastern, Southern and Western coastal zones of Sri Lanka, which were affected by the Tsunami wave, which hit Sri Lanka on the 26th of December 2004 are coral reefs, sea-grass beds, mangroves, lagoons, estuaries, marshes and sand dunes. Damages to certain coastal areas have been enhanced due to pre-tsunami anthropogenic activities, which have severely disturbed the natural eco-systems.

Impacts to coral reefs

Tsunami waves have caused serious physical damage to shallow, near shore coral reefs, which are located at depths less than 15 meters and such damages have been observed 50 days after tsunami by Mr. P.B.T.P. Kumara of Dept. of Fisheries Biology, University of Ruhuna, in Polhena and Mirissa, which are located within the coastal belt of Matara District. These physical damages could be due to the force of the tsunami waves and also due to the movement of large terrestrial objects that washed off in to the reef sites due to the tsunami wave. Considerable area of the shallow reefs were covered by debris and sediments, which caused stress to coral building organisms as a result of reduced light penetration, this is evident by occurrence of bleached corals in certain areas. In addition to the above tsunami waves may have brought pollutants from land in to the sensitive coastal ecosystems, which also may have resulted in stress to coral building and reef dwelling organisms.

Sediments which entered the coastal zone may have been of four types Terrigenous (originate from land), Biogenous (originate from living orrganisms), Hydrogenous (precipitated within water) and Cosmogenous (from meteorites). Hydrogenous and Cosmogenous sediments may have been transported from the continental slope or from the deep ocean floor in to the near shore marine and terrestrial ecosystems because the tsunami waves have a deep sea origin and it can push even heavier objects as a result of energy it carries. At the time of occurrence of the tsunami wave, North-East Monsoon currents were operating in the Indian Ocean around Sri Lanka. Due to the Southwest and Northeast Monsoon currents that operate in around Sri Lanka from May to September and from November to March there are seasonal variations in the currents operating around Sri Lanka. Generally coastal currents along the eastern coast are stronger than those of the west coast, which may have facilitated the distribution of sediments and debris in to a vast area during and after the tsunami.

The devastation due to tsunami was severe in Hikkaduwa, Seenigama, Thelwatte, Polhena, etc. in the southern coastal belt of Sri Lanka, which are also the areas subjected to harmful anthropogenic activities such as coral mining for lime production. The absence of coral reefs, that could have acted as barriers for strong waves have increased the damage caused by the tsunami waves. According to the mining regulations of Sri Lanka, although the closure of the pits in inland areas after mining is essential, most of the coral pits are left open after mining. Coastal private properties such as tourist hotels and houses and public properties such as roads and railway lines in Hikkaduwa, Seenigama and Telwatte were subjected to severe damage due to this reason and also due to the reason that some of these areas are situated below the mean sea level.

Sea grass beds

Sea grass beds are the least affected, which should be due to their root structure and shape of leaves, that helped them to withstand the strong wave actions in the coastal areas. Sediments and nutrient influx from terrestrial ecosystems as a result of tsunami waves may enhance the growth of sea grasses and other sea weeds. High nutrient influxes to enclosed coastal marine waters and bays may cause eutrophication, which will result in algal blooms, that can reduce the light penetration and hence the coral growth in these areas.

Impact of tsunami on the mangrove vegetation

Impact of tsunami to mangrove vegetation around Rekawa Lagoon could be considered as the best example from the southern coastal belt of Sri Lanka to explain the enhancement of damage from natural disasters due to the alteration of natural environment by man. In areas where mangrove vegetation has been replaced by coconut plantations the damage was rather severe. Causeway and the small bridge, which were constructed across the lagoon have acted as a barriers for the free flow of water, travelling upstream through the Rekawa Lagoon at the time of operation of the tsunami wave. Due to this reason and as a result of the enormous amount of energy carried by the tsunami waves the damage to the properties and vegetation around the lagoon has been very high. Tsunami waves have also caused severe damage to the causeway and the bridge that replaced a small part of the causeway across the Rekawa Lagoon. Magnitude of the force of the tsunami waves is evident by the movement of aquatic plants such as *Chara* sp, which were found hanging on the shrubs and trees in the vicinity of the lagoon. If there was a bridge across the lagoon, which would have allowed free transportation of water upstream, the damage to mangrove vegetation and the properties in the vicinity of the lagoon would have been less.

Sand dunes and its vegetation

Pre-tsunami disturbance of sand dunes and its vegetation due to human interference has enhanced the impact of tsunami wave in the Hambantota District. Wherever the sand dunes and their vegetation are undisturbed the damage due to tsunami was minimal. *Pandanus* sp., *Terminalia* sp. *Azadiracta* sp. and few other species, which belong to either dry zone flora or dune flora were commonly found on the sand dunes of Hambantota. *Padannus* sp., which bear stilt roots is a common to all sand dunes and they have acted as barriers and buffers to tsunami wave in almost all unaffected areas. Complete devastation of the Hambantota town was solely due to the removal of sand dunes and their vegetation. Other sand dune flora, such as *Spinifex* sp., *Ipomea pes caprae,* etc. which bear running stems and roots, that act as sand binders, stabilised the sand dunes and also played a major role in retaining the sand and reducing the damage and the erosion that may have occurred due to tsunami waves.

In most places, where *Casuarina* sp., an exotic plant, has been planted on the sand dunes, it has not acted as a buffer against the tsunami wave. On certain sand dunes, where young *Casuarina* trees were found, protection to a certain extent was observed because their branches were almost touching the ground. But in areas where the sand dunes were not present, *Casuarina* plantations were severely disturbed and they did not show any buffering action to strong waves and this was evident along the Beach Road in Matara. In *Casuarina* plantations, soil stability is not found, because of the slow degradation of *Casuarina* leaf litter, which does not support an under growth. In areas where natural sand dune vegetation was found, a thick undergrowth consisted of *Spinifex Sp.*, *Ipomea pes caprae,* etc. which can stabilise the sand dunes are found. Under growth in such areas, have been supported by a gradually degrading leaf litter, which also helps to stabilise the soil.

Post-tsunami destructive anthropogenic activities

Several anthropogenic activities have been observed along the southern coastal belt of Sri Lanka, that can cause severe damage to sensitive ecosystems that have been left unaffected after tsunami and they are as follows.

- **Dumping of rubble near the shore line and in to the coastal marine waters and unaffected ecosystems such as marshy lands**

  This can be hazardous because the rubble from tsunami may contain pollutants and toxic substances which may cause negative impacts on the sensitive coastal ecosystems. When they are stacked close to the shore line and dumped in unaffected terrestrial ecosystems, there is a danger of increasing soil salinity. During rainy weather they can be washed off in to coastal marine ecosystems such as coral reefs. These may even get leached into soil affecting the ground water.

- **Burning the rubble close to unaffected vegetation**

  This can increase the temperature in the area, which can cause further destructions in the coastal ecosystems.

- **Removal of disturbed and undisturbed dune sand for construction work**

  This can enhance coastal erosion as sand dunes are natural barriers for strong winds and waves, especially in the Hambantota District.

- **Filling disturbed coastal areas with soil transported from hinterland**

  This can cause further irreversible changes in the chemical and physical structure of the soil profile in the coastal area. In addition, to that if such soils are washed off in to coastal marine waters, their organic matter contents and nutrients can cause eutrophication in lagoons, coral reefs and sea grass beds resulting in algal blooms, that can in turn affect the light penetration in to reef areas.

- **Post-tsunami reconstruction of settlements within the coastal belt**

  This is a sensitive strip of land between the marine and terrestrial ecosystems, should be done according to an integrated coastal zone management plan. Any project undertaken without an integrated approach can be a failure & also may cause irreversible impacts on the coastal sensitive ecosystems. Removal of the top soil with the tsunami rubble and bulldozing has been carried out in most affected areas and this may enhance further erosion of the coastal terrestrial environment

Recommendations for restoration of damaged coastal ecosystems

- Organize community participatory cleaning programmes to remove the rubble collected on reef ecosystems to reduce the further destruction and bleaching of coral reefs
- Organize coral propagation and replanting programmes for damaged or disturbed coral reefs and declare such places as protected areas

- Prevent further destruction of sand dunes and allow the disturbed sand to resettle through natural means (through the activity of winds and waves)
- Replanting of naturally occurring species of trees and shrubs (e.g. *Pandanus* sp., *Terminalia* sp. *Azadiracta* sp.) on disturbed sand dunes and coastal ecosystems and maintain them as buffer zones
- Use of dune sand for construction work should be banned
- Reconstruction of coastal barriers, bridges across lagoons, estuaries, etc., ensuring least disturbance to the natural ecosystems
- Prevention of filling the coastal areas for beach parks, constructions for tourism industry that disturb the sensitive ecosystems, etc
- Promotion of eco-tourism.
- Bann destructive fishing operations (such as use of explosives) in coastal marine waters.
- Study the current status of coastal fish populations and if necessary declare protected areas to allow restoration of fish stocks

Recommendations for rebuilding and development of tsunami affected areas

- Identify the natural and anthropogenic factors enhanced the destruction from tsunami waves
- Identify the physical and biological nature of sites unaffected and identify the most suitable flora to be promoted or replanted in affected coastal areas and buffer zones to be declared in future.
- Prepare an integrated coastal zone management plan with due consideration to natural disasters that can occur in coastal areas
- Introduce a coastal buffer zone, after considering the important features of areas that are unaffected by tsunami and protected by natural barriers
- Ensure strict conservation of sensitive ecosystems such as coral reefs, sand dunes, mangroves, marshy lands, etc.
- Introduce suitable rehabilitation programmes for sensitive ecosystems that are disturbed
- Construction of coastal structures after studying the hydrodynamics of coastal marine waters and associated aquatic environments.
- Introduction of sea-weed farming, ornamental fish farming and other suitable small industries, as alternative lively hoods for those who are involved in coral mining.

COASTAL VEGETATION AND ITS PROTECTIVE FUNCTION

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A coast is unique as it is the boundary between land and sea where myriad processes take place. Naturally a coast is dynamic, its geomorphology changes continuously with the energy available in the waves, it is either eroded or accreted and it is occupied by man in numerous ways. A coast primarily serves two functions, it stops waves and stores sediment. Sand dunes and beaches are sediment stores while soft cliff profiles change during monsoon periods due to loss of sediment by the waves with high energy that reach it. Coastal landforms therefore are not permanent features, they constantly change over a variety of time scales, subjected to the environmental conditions at the time. A change in the conditions can take place naturally as the recent tectonic plate movement and consequent Tsunami of the Indian Ocean. Most often the changes are triggered by human activities initiated with poor perception of the dynamic nature of a coast. In coastal development planning, it is realistic and therefore prudent to view the coastal landforms as unstable features that are to be altered with changing coastal environmental conditions.

Coasts can be classified as wave dominated, tide dominated or wind-dominated, depending on the dominant process that is responsible in the formation of coastal landforms. Each dominant process is associated with distinct depositional environments as presented in Table 1.

Table 1:
The contrasting forms of agent dominance at the coast and their resulting landforms. (Hanson, 1988)

Wave dominated	Tide dominated	Wind dominated
Shore platforms	Mudflats	Sand dunes
Cliffs	Sandflats	
Beaches	Salt marshes	
Spits, tombolos	Mangroves	
Deltas	Deltas	

Wave energy

High ——————————→ Low

These coastal landforms support an array of plants. Wave dominated coasts show a zonation in plant distribution, i.e. the strand plants occupy the waterfront areas of the beach while herbaceous xerophytic plants take a more hinterland position. Supratidal part of the coast accommodates taller shrubs and trees such as *Scavola tacada* and *Pandanus tectorius.* Tide dominated coasts are those that occur along sheltered shorelines along lagoons and estuaries, where wave action is at its least. Energy associated with the waves is lows that clay and silt get deposited in the shallow intertidal and subtidal areas. Plants that occur in such coastal landforms are unique, as they are adapted to live in this unstable saline environment that becomes anaerobic at high tide. Mangroves occupy the intertidal areas while seagrasses occur in the subtidal part of the coast. Salt marshes are unique to intertidal areas of arid coasts where soil salinities are very high.

Wind dominated coastal landforms do not directly depend on waves and tides for their formation. Sand dunes are formed as a result of sand transportation from intertidal areas to supratidal areas by wind and it requires sand to be delivered to the coast and strong onshore winds. Wind velocity and moisture content of sand in the intertidal areas are crucial for sand dune formation, which in turn depend on the tidal range, presence of a wide and shallow foreshore and a dry climate. Sand dune vegetation predominates by grasses.

Vegetation associated with coastal landforms is of immense importance for their stability. Plants with their adaptations such as prop roots, pneumatophores and deep penetrating tap roots, consolidate the sediment leaving poor opportunity for the waves to transport them. Besides, plants act as barriers that dissipate energy of the waves so that less energy is available to erode the coast. Dune vegetation captures sand and contributes to its vertical growth and enhances the protective function, of this natural structure, particularly on high-energy coasts. Mangroves and salt marshes also consolidate sediment (fine sediment) with their unique roots, hence they check erosion in estuaries and lagoons while serving as a wind barrier that protects the hinterland. Sufficient evidence to this effect is available in the aftermath of Indian Ocean Tsunami.

Despite the protective strength of the coastal vegetation it is constantly being under threat. Except in the national parks, coastal vegetation is subjected to human pressure for varying degrees. Mangroves are particularly destroyed for urban expansion hotel construction, human settlements and shrimp farming. Strand vegetation is non-existent on some coasts as they have been replaced by other land uses. In a few lagoons such as Negombo and Chilaw, mangroves are cultivated and protected by the local communities.

State decision to establish a 100m buffer zone at the seafront of the coast is timely and prudent. Reinforcement of its protective function with appropriate plant species with a utility value is wiser. It will not only save expenditure on coastal protection but also give us an opportunity to use locally available resources for the purpose. *Pandanus tectorius, Terminalia catappa,* species of *Syzygium, Muntinga, Cassia, Acacia and* mangroves can be used for the purpose as they are already available in Sri Lanka and their propagation methods are known and easier to adopt. Despite the unprecedented destruction of life and property that Tsunami has caused, it also has given us a golden opportunity for a paradigm shift, one that saves the nation from debt trap entailed with multimillion dollar- hard engineering solutions that have proven worthless again.

References

Hanson, J.D., 1988. *Coasts*. Cambridge University Press, Cambridge.

ENVIRONMENT AND POLITICS

The environment is intimately linked to politics. People not only live in the environment but they use the environment as resources for their living and to raise their standard of living. Unwise use of resources have caused environmental problems from local to global level. The effective solutions to these environmental problems cannot be found without direct political interventions at local, national and global levels.

More importantly, the human groups claim ownership of different parts of the environment through such concepts as villages, towns, homelands, provinces and finally states. Over the years human groups have divided the environment and compete for the resources/environment and frequently these groups have gone to war over the ownership of environment.

Politics has been famously defined as who gets what, when and how (Laswell). In the final analysis it is politics that decide the future of the environment. What is to be protected, reserved and used are all products of political ideologies and belief which translate into environmental policies of respective governments. Science helps us understand environment. Arts helps us appreciate the environment. But it is politics that controls the environment for us and for the future generations.

The next issue of the ***Eco-Sri Lanka Magazine*** is devoted to the broad theme of Environment and Politics. Prof. Shantha K. Hennayake, Coordinator of the Center for Environmental Studies, University of Peradeniya will provide the theme paper. You are invited to submit essays, articles and short notes on any topic related to the broad theme of environment and politics to Editorial Board, Eco-Sri Lanka, Central Evnironmental Authority.