

**An environmental perspective of post-tsunami scenario along
the coast of Tamil Nadu, India: role of sand dunes and forests**

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Abstract

An endeavor to feel the pulse of a coast devastated by a powerful oceanographic event is made. Results of field investigations along Tamil Nadu seaside revealed that the tsunami of December 2004 demolished dwellings within strips ranging from 6 to 132 m (average width, 41 m) from the dune, and flooded up to 862 m (average, 247 m) from the shore. The event damaged sand dunes, ripped dune vegetation, created new water bodies and shattered high value assets. Comparatively, casuarina forests performed remarkably. Uprooting of trees was exclusively restricted to a frontal strip ranging from 5 to 25 m (average width, 14 m) nearest to the shore where the maximum wave run-up was 6.5 m above sea level. Sand dunes in general, and casuarina forests in particular, possess an innate capacity to dissipate powerful waves. This inference is supported by: (a) negligible over wash along belts characterized by high dune complexes, (b) intact villages shielded by dense forests as well as sand dunes, and (c) maximum destruction of open beach front influenced by intense human activity. In this context, the Coastal Regulation Zone (CRZ) Notification of 1991 offers sufficient scientific validity to be endorsed. However, post-tsunami ecosystem management initiatives lack a scientific basis. Therefore, a coastal hazards policy, that considers adaptation, dune restoration and forested buffer zones, is a sustainable long term option for Indian coasts.

Keywords: Tsunami, coastal regulations, sand dunes, coastal vegetation, natural hazards, Tamil Nadu, India

1. Introduction

In the aftermath of the December 2004 Indian Ocean tsunami, the socio-economic havoc was unprecedented. The Indian National Crisis Management Committee looks after mitigation of disasters and recommends strategies for preparedness, quick response, strategic thinking and prevention. However, the tsunami tragedy caught experts unawares (Krishna, 2005a).

Similarly, following the attack by hurricane Katrina, scarce cooperation between policy makers, scientists and citizens was noted. The scientific research results dealing with mapping of hazardous coasts never benefited the public. Hence, coastal scientists have not fulfilled societal obligations by warning implications of beachfront development (Pilkey and Young, 2005).

What Katrina did to the US coast, recurring hydrometeorological events have inflicted on the Indian east coast year after year (Shrestha, 1998; Thapliyal et al., 2000; Mani, 2000; Raghavan and Sen Sarma, 2000; Mascarenhas, 2004). The loss of life and property is overwhelming (see Mascarenhas, 2006) and the monetary loss is enormous (Table 1). In view of the above, the tsunami that demolished large parts of the south Indian sea front is yet another reminder that all is not well with the way Indian coasts are developed and colonized.

After the December 2004 tragedy, the National Institute of Oceanography, Goa, conducted a survey along the Tamil Nadu coast of India (Fig. 1). Various evidences were documented in January 2005. This effort was continued in April 2005, October 2005 and January 2006. A national workshop organized in February 2005 proposed a science plan for hazard preparedness (Krishna, 2005b).

With reference to Tamil Nadu coast, this communication addresses the post-tsunami situation mostly based on an analytical perspective of field observations supported by relevant measurements. The paper describes the tsunami onslaught on the coast, affirms how the presence of sand dune belts and associated forests came to the rescue of habitations and humankind and discusses problems that ail coastal management by depicting a field situation of the recovery process. A need for a coastal hazards instrument is felt.

2. Background: prevailing coastal policy

Haphazard anthropogenic activity along the coastal stretches during 1980's compelled the Government of India to issue instructions to all the coastal states about the eventual effects of inappropriate sea front development. The famous order stressed the environmental value of sandy beaches, by suggesting that coasts be kept clear from all human interference up to 500 m from the high water line. This directive marked the beginning of an endeavor towards protecting the health of Indian coasts.

In 1991, the Ministry of Environment and Forests (MEF), Government of India, declared coastal stretches of seas, bays, estuaries, creeks, rivers and backwaters which are influenced by tidal action (in the landward side), up to 500 meters from the High Tide Line (HTL) and the land between Low Tide Line

(LTL) and HTL, as Coastal Regulation Zone (CRZ). The CRZ Notification comprises four main categories (MEF, 1991):

- CRZ I includes (a) areas that are ecologically sensitive and important, such as national parks, marine parks, sanctuaries, reserve forests, wildlife habitats, mangroves, coral reefs, areas close to breeding and spawning grounds of fish and other marine life, areas of outstanding natural beauty, historical / heritage areas, areas rich in genetic diversity, areas likely to be inundated due to rise in sea level consequent upon global warming and such other areas as may be declared by the Central Government or the concerned authorities at the State level from time to time; and (b) area between the LTL and HTL.
- CRZ II comprise sectors that have already been developed up to or close to the shoreline; these are “developed areas” referred to as those within municipal limits or in designated urban sectors which are already “substantially built up” and which has been provided up with drainage, approach roads and other infrastructure facilities such as water supply and sewerage mains.
- CRZ III refers to areas that are relatively undisturbed and which include coastal zone in rural areas (developed and undeveloped) and also urban areas which are not substantially built.
- CRZ IV only comprises insular stretches of Andaman, Nicobar, Lakshadweep and small islands. This category is not applicable to offshore islands of peninsular India.

The main essence of the notification was to control and minimize environmental damage to sensitive coastal ecosystems including estuaries and backwaters from unplanned human interference. Accordingly, no new constructions are permitted up to 500 m from HTL in CRZ I and up to 200 m in CRZ III. For rivers and backwaters, the setback is 100 m or width of creek whichever is less. The notification imposed restrictions and formulated guidelines for various coastal activities. It lists various prohibited activities, regulation of permissible activities, procedures for monitoring and enforcement, coastal area classification and development regulations, norms for regulation of activities and detailed guidelines for the development of beach resorts and hotels. This order is the prevailing law that governs developmental activities along coasts, rivers and backwaters of India.

The CRZ (MEF, 1991) has placed India amongst the select countries in the world to frame laws to legally protect sensitive coastal ecosystems from unscientific development. However, frequent complaints have led to its validity being questioned and the instrument being subverted. In the meantime, misuse of coastal spaces forced some environment conscious citizens to file a public interest litigation. After considering the merits of coastal zone issues, the Supreme Court of India validated the CRZ Notification through an order of 25 April 1996.

Despite the ruling of the apex court, inappropriate coastal development, by ignoring mandatory setbacks, continues unabated. As such, there appears to be no sustainable solution in sight even 15 years after CRZ was formulated.

3. Methods

Post-tsunami surveys were carried out along the coast of Tamil Nadu from Chennai in the north to Vedaranyam in the south. A total of 24 major locations were investigated (Fig. 1). Several other intervening sites (not shown in Fig. 1) were also studied. The survey consisted of ascertaining the inundation limits, run-up heights at different locations and measurement of cross section profiles. Damage to coastal dwellings and impact on vegetation was also assessed.

The inundation limits were confirmed from visual observations like water marks on the walls of houses, the debris line left by receding sea water and also information gathered from the local inhabitants. Its geographical position was noted using a hand-held Global Positioning System. The run-up is the height of the maximum inundation limit with respect to the shoreline level. The run-up height was estimated from the cross sectional beach profiles. As the profiles are measured at a different time compared to the actual event, the profiles and the run-up heights were reduced to the Chart Datum.

With reference to local water level at the time of measurements, beach profiles along the line of sight were taken from the water line till the tsunami inundation limit. A surveyor's Dumpy Level (Karl Zeiss) and a graduated staff were used to record beach heights. These levels were reduced to the Chart Datum, calculated from the time of observation of the water line and the corresponding predicted-tide. The predicted-tide for different locations is obtained by linear interpolation of tides between known tidal stations in the study region. In general, profiles were measured at an interval of 5 m. Larger distances were considered where the beach is flat whereas smaller intervals were used where the beach is undulating with features like dunes, ridges or valleys. Beach profiles were taken till the inundation limit wherever this point was accessible for survey equipment. The locations where the beach profile did not reach the maximum inundation limit were Samanthanpettai, Tarangambadi, Poompuhar, Thirumallaivasal, Thoduvai and Kodiyampalayam.

In addition, various types of impacts of the tsunami on coastal landforms were noted (Table 2) and the width of strips of broken houses and injured vegetation were measured (Table 3).

4. Coastal imprints of December 2004 tsunami

Tsunami run-up levels ranged from 0.7 m to 6.5 m above sea level and flooding varied from 31 m to 862 m from the swash zone (Chada et al., 2005; Jayakumar et al., 2005; Ramanamurthy et al., 2005). The average inundation was around 247 m. In comparison, global ocean tsunamis indicated run-up of 14.3 m with flood limit of 200 m in New Zealand (Nichol et al., 2003), a run-up of 11.7 m and water penetration of 700 m inland in 1908 in Italy (Tinti and Armigliato, 2003), wave heights that reached 9.5 m causing inundation up to 300 m in 1994 in Java (Maramai and Tinti, 1997) and run-up of 2.5 m and inundation of 100 m in 1999 in Turkey (Altinok et al., 2001).

The tsunami extensively transformed the landscape of Tamil Nadu coast. The changes and the scenario that emerged (Table 2) are briefly discussed below.

4.1. *Exceptional performance of casuarina trees:* Most remarkably, coastal casuarina plantations survived the tsunami invasion (Mascarenhas, 2006). Only frontal casuarina strips were attacked, bent, and stripped of its leaves by wave up-rush (Table 3). Similarly, the coconut groves and date palm trees remained intact. At Poompuhar, all the original palm trees are standing. Such a phenomenon was also confirmed at Vada Nemelli, Mahabalipuram, Nanjalingampettai, Silladi, Nagapattinam and north of Velankanni along Tamil Nadu coast, and Periyakalpet and southern Karaikal in Pondicherry.

4.2. *Destruction of beach front dwellings:* Loss of life and property was identified only along the frontal strip ranging from 6 to 132 m from the dune line (Table 3). All houses and particularly huts located on frontal dunes at Uroor Kuppam, Periyakalpet, Devanapatnam, Tarangambadi, Nagore, Samanathanpettai and Nagapattinam were demolished in totality. The worst affected was the Keechankuppam – Akkaripettai village strip of around 2 km where stone-walled houses were razed to rubble. Improvised shops and thatched structures in a 75 m wide strip at Velankanni were washed off completely.

Identical scenes of shattered dwellings were reported from other coasts of mainland (Chada et al., 2005) and the Andamans (Ramanamurthy et al., 2005). Globally, severe damage was observed in the villages of coastal Java (Maramai and Tinti, 1997) in 1994. Likewise, coastal dwellings in Sicily and Calabria (Tinti and Armigliato, 2003) were completely leveled by the violent tsunami waves in 1908.

4.3. *Damage to sand dunes:* Coastal geomorphic features displayed various degrees of obliteration. Over topping and over wash was noticed at places, as evidenced by wave-induced gaps along the dune ridges, and by dead wood debris flung behind dunes. Frontal sand dunes were flattened (Nagore), some were breached (Silladi), and others were eroded (near Nagapattinam lighthouse). A 30 m long dune at Samanathanpettai, although dissected, stands witness to the power of high waves.

Dune heights were lowered by 2 m and a 6 m high dune was razed into a flat sandy area at Cuddalore; whereas at Poompuhar, 1 m sand was removed, dunes were breached and leveled over 100 m into a lagoon (G.V. Rajamanickam, pers. comm.). Along the Kerala coast, the beach-dune system showed volume changes ranging from 4 to 91 m³ (Kurian et al., 2006). Elsewhere in the world, erosional escarpments up to 2 m high were recorded on beaches of Java after the 1994 tsunami (Maramai and Tinti, 1997).

4.4. *Deracination of dune vegetation:* Dune plants were uprooted and removed, often leaving no trace of frontal dune vegetation. The most affected dune vegetation comprises 'ipomoea' creepers and 'spinifex' that carpet frontal sand dunes. At Uroor Kuppam near Chennai, around 90 m wide beach stretch was found with uprooted and shredded ipomoea creepers. At Nanjalingampettai, spinifex was uprooted, whereas at Nagore and Silladi, there were no signs of any living green material on damaged dunes.

4.5. Formation of new water bodies: A permanent saline water body that now occupies a former flood prone low beach at Kallar is a characteristic feature. A new feature in the form of a narrow inlet connects the lagoon to the sea. The lagoon has linked itself with the existing river inland. A similar phenomenon, on a lower scale, was identified at Silladi resulting in the road to beach being cut off by the new lagoon. Invasion of saline water on antecedent lowlands was frequently reported following major storm surges along the east coast of India (see Mascarenhas, 2004) and following major storms in the US (Dolan and Davies, 1994; Pilkey et al., 2000).

4.6. Passageways of tsunami: It is pertinent to note that roads perpendicular to the beach served as a passages for tsunami to travel inland, as in Nagore, Silladi, Nagapattinam lighthouse and opposite the shrine at Velankanni. This process was noted wherever roads touched the beach.

Similarly, gaps on dunes, mostly created by trampling, and inter dune valleys contributed to overtopping, over wash and tsunami advance as noted at Nanjalampettai. Sea water reached 372 m inland. Similar observations were reported at several sites on Indian coast after the 2004 tsunami (Chada et al., 2005). Creeks and inlets along the sea front proved vulnerable. Opposite Nagapattinam lighthouse, the inlet promoted tsunami movement by flooding a village 2 km away. Likewise, the tsunami traveled more than one kilometer inside the river at Karaikal.

4.7. Black sand deposits: A conspicuous heavy mineral rich black sand seam was exposed on the beach at Nagore, Silladi and opposite the lighthouse at Nagapattinam. In addition, our field surveys also revealed a distinctive black sand carpet deposited at Karaikal and Poompuhar. It is not known whether mineral sands were transported, deposited or exposed by the event. The appearance of black sands is a unique process provoked by the Indian tsunami.

4.8. Reworked debris: Our observations revealed a red clayey deposit more than 100 m inland at Periyakalpet (Pondicherry). Gravel, large shells, sand and dead wood was common. Gravel was also reported 60 m inland at Tarangambadi whereas sand was found up to 430 m from the swash zone of Nagapattinam (Chada et al., 2005). Displaced roof tiles, broken masonry, wooden pieces, tree branches and dead wood were routinely noted as backshore occurrences during our surveys.

In comparison, large boulders are associated with severe tsunamis, where run-up processes resulted in the deposition of sediment sheets. A storm deposit extends about 40 m inland as opposed to about 200 m for the 15th century tsunami of New Zealand (Goff et al., 2004). Granule to cobble-sized deposits were located on a dune of a coastal barrier in Whangapoua Bay, New Zealand, in addition to a gravel sheet extending 200 m landward from the beach (Nichol et al., 2003).

4.9. Damage to high value facilities: At Nagapattinam, the tsunami over topped and shattered the sea wall of the fishing harbor, trawlers were tossed ashore, a communication tower crashed, and oil storage tanks suffered erosive damage. High waves dislodged another sea wall at Karaikal where an arched column of a heritage bridge came down. A children's park and tourist facilities disappeared at Cuddalore beach.

5. Performance of coastal sand dunes and vegetation

5.1. Sand dunes and beach morphology

Evidence gathered in the field confirms that coastal geomorphic features such as sand dunes played a defensive role in the wake of the tsunami along Tamil Nadu coast. To substantiate the role of coastal dunes, five profiles representing different settings are presented (Fig. 2).

Uroor Alcott Kuppam: South of Chennai, although the beach is relatively flat, a 2 m high compound wall was spared by 5.0 m run-up, owing to a 4.5 m high dune. A steep gradient with thick bushes in front gave additional protection. No destruction was observed here. In comparison, around 0.5 km south, all beach huts were leveled.

Nanjalingampettai: The coast is characterized by dunes more than 5 m high and very steep seaward gradients. The wave up-rush of 3.7 m stopped at the dune. Inundation of 372 m is attributed to over wash through gaps on dunes due to trampling. It is pertinent to note that there was no damage to any habitation behind dune complexes; coconut trees and casuarinas also acted as natural protection.

Tarangambadi: The sea shore was occupied by dense dwellings. Sand dunes were flattened in favor of houses. The wave run-up of 2.4 m bypassed the flat beach thus razing whatever came its way. Inland inundation was 401 m. Coast perpendicular roads over dunes contributed towards the invasion of tsunami waters. As they lacked natural protection, all the beach front houses disappeared.

Samanthanpettai: The beach is characterized by high dunes and appreciable seaward gradients. The wave up-rush of 3.2 m induced inundations up to 150 m. Although frontal houses were demolished, assets behind dunes remained intact due to the natural buffer protection offered by sand dunes. As a better example, 3 km south at Nambiar Nagar, higher dunes and trees gave complete protection to an entire village where only one house, located on a dune, crashed.

Velankanni: The beach was colonized by rows of make-shift structures for which sand dunes were leveled. The wave run-up of 3.9 m over shot the flat beach with a complete removal of structures. The coast-perpendicular road helped the invasion of tsunami waters. Inundation was observed 325 m inland. All the beach front shops, over a beach width of 100 m, were washed off in totality due to absence of natural protection. Around 900 deaths were reported at this pilgrimage site.

Dune fields have offered natural protection in the wake of extreme events (Dolan and Davies, 1994; Clark, 1996; Pilkey et al., 2000; Nordstrom, 2000; Brown and McLachlan, 2002). Inundations and destruction of habitations, dwellings and resorts during extreme events, as a result of human interference on sand dunes in West Bengal, is documented (Paul, 2001). Being vulnerable to human interference, sand dunes are protected under CRZ. Hence the need to conserve and nourish dunes by allowing them to migrate, develop and evolve freely and naturally in form and space.

5.2. Casuarina forests

Large stretches of Tamil Nadu coast are marked by luxuriant casuarina forests. Thickly vegetated stretches displayed exceptional resilience by dissipating high waves. Field measurements reveal that only the frontal strip ranging from 0 to 25 m were twisted, bent and stripped of leaf cover (Table 3). The average width of damaged trees equals 14 m for a stretch of coast where the wave run-up was as high as 6.5 m above sea level. Only a few trees that faced the open ocean were uprooted and hence suffered the most (Fig. 3). At some places however, casuarinas were hardly affected.

Similarly, coconut trees also showed an appreciable resistance against wave attack. Although located dangerously close to the beach, coconut plantations remained intact in entirety. Nagore can be cited as an example where flood waters penetrated 860 m inland (Jayakumar et al., 2005), and dwellings up to 132 m from the dune line were destroyed. Here, all coconut trees survived. Palm trees displayed a similar reaction. At Poompuhar, all the original 19 palm trees are standing. This hypothesis reiterates that casuarinas in particular play a role of effective agents of energy dissipation against violent waves (Mascarenhas, 2004, 2006).

Casuarina and mangrove forests protected the shoreline of Cuddalore against tsunami waves (Danielsen et al., 2005). Only 5 to 10 trees nearest to the shore were uprooted. These observations are in conformity with our field based evidence described above (Fig. 3). Sea water intrusion was negligible in areas covered with thick vegetation, and damage was less on shorelines lined by mangroves (Chada et al., 2005; Roy and Krishnan, 2005) as compared to bare lands of Andamans (Jain et al., 2005). Villages shielded by forests remained intact (Danielsen et al., 2005). Experimental studies have shown that mangrove forests attenuate wave energy. Dissipation of waves depends on the density of forests and the diameter of tree trunks. Currents thus flow around rather through the forest (Furukawa et al., 1997).

Observations also have revealed that Sunderban mangrove of Bengal suffer less from wind and surges (Ali and Chowdhury, 1997). The defensive role of mangroves during cyclones has been demonstrated at Bhitarkanika (Badola and Hussein, 2005), and by post-cyclone imageries of Orissa coast (Nayak et al., 2001). Casuarina trees often erode during storms but survive wind speeds of 100 km per hour (see Mascarenhas, 2004). This evidence supports bio-shields as efficient energy dissipaters during powerful oceanographic events.

6. Post-tsunami recovery and coastal management initiatives

One year after the tsunami disaster, significant rebuilding activity was noted along the coast of Tamil Nadu in January 2006. Some of the observed processes and current management efforts are analyzed.

Natural restoration processes: Natural restoration was identified as follows: (a) Dune vegetation that was torn to shreds by the tsunami is actively growing in January 2006; at places, the entire backshore that was devoid of creepers one year ago, is presently characterized by a rich carpet of ipomoea creepers, (b) Exposed in December 2004, black sands were being covered by wind blown sand in April 2005, an indication of natural rebuilding of eroded material; in January 2006, black sands were no longer visible, (c)

Remarkably, casuarina trees that were bent by tsunami impact have bounced back to life; in January 2006, casuarinas have rejuvenated all along the coast, (d) Several inlets created by the tsunami appear to be closing by wave action and eolian sand movement; further empirical evidence is needed. In short, sufficient evidence can be forwarded in favor of natural rebuilding of Tamil Nadu coast.

Beach profiles of 5 sites (Fig. 2) measured in April 2005 and January 2006 indicate: (a) No change in the beach face slopes at any location, (b) Erosion of the beach at all sites, (c) Frontal berm has receded every where except Tarangambadi, (d) A maximum recession of 28 m, (e) Prevalence of aeolian transport of sand at most of the places in January, (f) Elevation of beach with wind blown sands at places, (g) Ephemeral streams linked to the sea during April are cut off with accumulated sand. Most of these effects are attributed to natural seasonal changes of beach evolution.

Planting coconut trees on the beach: During our surveys in April 2005, at Akkaripettai, we identified several rows of coconut saplings planted on the beach close to the waterline. An existing dune was razed, and a “sand barrier” was created for protection, along the water line. A panic reaction lead to improper selection of sites. In January 2006, the “barrier” was gone, an erosive scarp took its place, and all the coconut saplings were dead. A lack appropriate management guidelines is evident.

Afforestation of Mahabalipuram coast: Vast sandy stretches from Chennai to Mahabalipuram are presently under the spell plantation programs. Thousands of casuarina trees have been planted on the bare dunes impacted by the tsunami. However, at several sites as in Silladi, casuarinas are planted too close to the beach.

Inland trees at Nanjalimgampettai: Hinterland vegetal species is planted along the beach. Being too close to the coast, the ‘tree guards’ act as obstacles where wind blown sand is trapped. Small mounds of loose sand have almost buried each of these plants. As such, it is doubtful if these saplings will survive. This is yet another case of inappropriate methods of afforestation.

Dune vegetation: At some sites, the typical dune plants ‘spinifex’ was noted. Planting these species on damaged dunes is however noteworthy.

Implications of haphazard planting: The methods adopted for greening the coast leaves a lot to be desired. In the past, wrong trees were fixed at wrong places. Interestingly, at Mahabalipuram, casuarinas were unharmed, whereas acacias in the same cluster did not survive. Obviously, the selection of species for coastal afforestation lacks prudent planning.

Resilience of sea walls: The tsunami over topped the sea wall at Nagapattinam port. The one at Karaikal was also uprooted over a length of around 250 m. Hard structures have routinely failed in the wake of oceanic forces (Ali and Chowdhury, 1997; Paul, 2001), as these embankments did not save themselves during storms (Dolan and Davies, 1994; Ragahvan and Sen Sarma; 2000) or during tsunamis (Kurian et al., 2006). Despite adverse impacts, the boulder wall at Pondicherry city is widened, and the one at Nagapattinam port is being rebuilt in concrete, at a high cost, as a taller and longer fortification.

(Re)construction efforts: Our surveys in January 2006 indicated active rebuilding activity along shore lines. Rapid reconstruction of houses, on the same foundations, was noticed at Akkaripetai where the tsunami had wiped off an entire village just a year ago. Similar situations were observed near Chennai, Periyakalpet, Devanapatnam, Tarangambadi and parts of Nagapattinam and Kallar. The worst scenario was noted at Velankanni: all the make-shift restaurants, thatched shops and shacks, washed off in totality in December 2004 are back in January 2006. It is business as usual at this pilgrimage site.

Need for functional bio-zones: A progression of vegetal species landward from the dune forms a functional forested buffer zone (Clark, 1996). Herbs on the dune, shrubs on hind dune, followed by bushes and trees further inland form a gradation of vegetation and a natural slope. Such a bio-zone induces winds to deflect upwards and onrushing waves to loose energy. As such, barren strips have to be reserved for afforestation; sea side strips can be acquired and converted into recreation parks, forests, gardens, agriculture farms or wild life sanctuaries (Valdiya, 2001).

The rebuilding process reveals some positive, but mostly negative trends: (a) Although afforestation efforts are laudable, the standards of monitoring and compliance are often inadequate; hence restoration efforts fail (Legg and Nagy, 2006), (b) Our policies permit the reconstruction of a smashed structure in the same form and location as before, (c) Rebuilding permission is rarely sought, (d) Rebuilding projects do not undergo any scrutiny, (e) The scientific community has to decide whether hard protection structures are sufficient, or whether beach restoration is a sustainable alternative.

7. Conclusion

It was hoped that the tsunami would boost coastal hazard policies; this aspiration has not come about. The Indian coastal science fraternity is not able to reach a consensus on how to react. CRZ laws guarantee protection to lowlands susceptible to rise in sea levels due to global warming, but do not reckon wave run-up and flooding due to abnormal transgressions. The existing instruments are found deficient in the wake of inundations following extreme oceanographic events (Mascarenhas, 2002, 2004, 2006). The threat therefore persists.

Although CRZ notification regulates development, the country does not have a coastal hazards policy. Multiple factors are responsible for recurring coastal disasters: (a) non implementation of existing policies, (b) breakdown of enforcement, and (c) lack of post-disaster redevelopment guidelines. A lack of science - policy connection and fragmented policy approaches (Damodaran, 2006) affects coastal management in India. Hence the need to devise new regulations, revamp enforcement mechanisms and revise implementation strategies.

The inhabitants of coastal Tamil Nadu lost their lives because they were occupying landforms that they were not supposed to alter. The prevailing CRZ laws prohibit indiscriminate use of sea side spaces; sand dunes are fully protected from human interference under the CRZ.

Loss of life due to the tsunami invasion occurred up to 132 m, mostly from the dune line. This stretch (of 41 m average width) contained most of the destroyed dwellings inhabited mostly by the fishing community. Since CRZ is routinely violated, these constructions lacked designated setback and consistent natural protection. As such, complete destruction of sea front houses and make-shift structures occurred in Tamil Nadu. In contrast, coastal vegetation and villages behind dunes and forests remained unharmed. By analogy therefore, vegetation should have occupied sand dunes, strips where people actually lived.

Coastal management has to rely on scientific results to find sustainable answers to coastal problems (Koningsveld et al., 2005), wherein scientists, policy makers and stakeholders participation can lead to 'science for citizens' (Robertson and Hull, 2003). The role of national government in setting policies to guide decision-making process by engaging the people is a good practice (Olsen et al., 2005; Damodaran, 2006). Scientists have often felt that policy is another world, a notion that explains differences between science and policy (Cortner, 2000). In India, the science - scientist - policy interaction is in its infancy; the public is rarely involved.

The major thrust after disasters in India has been on mitigation. Instead, adaptation (Klein et al., 2001) advocates mandatory setbacks, no development zones and relocation inland. A public policy instrument has to: (a) consider options for adaptation against, rather than mitigation of, coastal hazards, and (b) adopt measures for restoration of coastal sand dunes with sufficient forested shelter belts backshore. These strategies are recommended as the most appropriate, long term, sustainable management solutions for Indian coasts.

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Table Legends

Table 1. Economic loss and reported deaths following some of the extreme oceanic events along the Indian east coast over the last 54 years (Source: see Mascarenhas 2002, 2004, 2006, and references therein).

Table 2. A summary of landform changes and impacts recorded after the tsunami of December 2004 along the sea front of Tamil Nadu, and landscape changes and human activities noted in January 2006.

Table 3. Characteristics of some of the locations, from north to south along Tamil Nadu coast, where post-tsunami damage studies were carried out. Beach width (April 2005) is measured from the water line to the base of dune. Damage to dwellings refers to the strip of housing colonies, measured physically, mostly from the dune line; the same applies to plantations. Figure 'zero' signifies that damage was nil.

Figure Legends:

Fig. 1. Stations along Tamil Nadu coast where post-tsunami surveys including beach profiles were carried out. Five of these profiles are discussed in this paper.

Fig. 2. Beach elevation and morphology of 5 coastal sites measured in April 2005 and January 2006. The arrow indicates run-up height of the tsunami of December 2004.

Fig. 3. Casuarina plantations performed remarkably as absorbers of energy from violent waves. 3A: at Karaikal, only a few trees from the sea facing strip of coast are bent or uprooted (April 2005); 3B: at Vada Nemelli, 15 km north of Mahabalipuram, a majority of these trees have revitalized and are sprouting after one year; sand dune vegetation is also recuperating (January 2006) (Photos: A. Mascarenhas and S. Jayakumar).

Table 1

Year of event	Place	Inland inundation (km)	Overall monetary loss (crore rupees)	Human loss
November 1952	Nagapattinam	8	6.00	400
October 1955	Kalingapatnam	-	1.00	-
November 1955	Rajamadam	16	-	500
December 1964	Rameshwaram	-	8.00	900
October 1967	Puri	25	>1.00	~1000
November 1969	Kakinada	9	110.00	~900
October 1971	Paradip	10-25	>1.00	~10000
December 1972	Cuddalore	-	40.00	80
November 1976	Madras	-	7.00	95
November 1977	Nagapattinam	-	155.00	560
November 1977	Nizampatnam	8-15	350.00	10000
October 1983	Bheemunipatnam	-	520.00	120
October 1987	Ongole	-	34.00	48
November 1988	24-Parganas	-	02.79	-
	Medinipur	-	06.36	-
May 1989	24-Parganas	-	56.69	485
	Medinipur	-	02.37	-
November 1989	Kavali	1-2	-	69
May 1990	Machilipatnam	16	~2248.00	967
November 1991	Cuddalore	<1	323.00	201
December 1993	Karaikal	2	-	111
May 1995	24-Parganas	-	44.17	-
	Medinipur	-	23.86	-
November 1996	Kakinada	-	150.00	2000
August 1997	Digha - Haldia	-	89.17	400
October 1999	Balasore-Paradip	35	>2750.00	9885
August 2000	Kakinada	-	776.75	131
December 2004 (tsunami)	Pondicherry/	0.24	512.00	107
	Karaikal	0.20		484
	Cuddalore/	0.37	2730.00	606
	Nagore/	0.86		6629
	Samanthanpettai/	0.15		
	Nagapattinam	0.80		
	Velankanni	0.32		~900

Table 2

Coastal features	Landscape changes and impacts after the tsunami (April 2005)	Reasons / activities responsible for impacts / human tragedy	Changes and human activities noted in January 2006
Sand dunes	Dunes were breached, eroded or flattened; over wash was noted at existing dune gaps	Natural impacts: dunes bore the brunt being nature's first line of defense	Damaged sand dunes are being replenished naturally by wind blown sand; a slow process
Dune vegetation	Uprooting of herbs and shrubs was common	Natural impacts of an extreme event	Dune vegetations has regenerated; long strips are fenced for plantation
Coastal plantations	Casuarinas remained intact; frontal few trees were ripped and bent; coconut groves and palm trees survived; acacias died	Trees acted as biological buffers against wave attack	Affected casuarinas have rejuvenated; bent trees are sprouting; other trees are doing well; large areas are taken for afforestation
Water bodies	New lagoons and persistent water bodies were formed; new inlets were observed	Natural impacts of an extreme event	Some lagoons seem to be a permanent feature; some are cut off from the sea
Sedimentary debris	Vast stretches of mineral-rich black sands were exposed; sand gravel and shells were found behind dunes	Origin of black sands is not determined; inland deposits were carried by over wash due to wave run-up	Black sands are covered by wind blown sand, at places in totality
Dwellings	Houses were shattered, and huts on dunes were washed off; improvised wooden shops vanished; some villages were wiped entirely	Crowded houses were built too close to the shore; absence of buffer zones; impacted by direct wave attack; flouting of coastal regulations	Hectic rebuilding activity is observed at places; make-shift huts are back; most houses are rebuilt on former foundations; coastal setbacks are ignored
Seawalls and bridges	Sea walls were overrun, dissected and dislodged by waves; a bridge column 1 km upstream was dislocated	There is no way to protect a sea wall from direct hit by high waves	New, longer and higher concrete sea wall is under construction at Nagapattinam port
Towers and tanks	Oil tanks were undermined by waves; high value towers crashed; electric poles were twisted	Storage tanks did not have any natural protection; towers were located too close to the coast	Eroded foundations are restored; two towers are noted instead of one
Fishing activities	Trawlers and canoes were tossed ashore	Fishing port was not a sheltered one; fishing business paralyzed	Fisher folk has resumed activities with new craft
Coastal roads	Coast-perpendicular roads are covered by transported sand	In appropriate planning of narrow roads; acted as pathways for tsunami propagation inland	Roads are obscured by sand

Table 3

Coastal site	Beach width (m)	Damage to dwellings / huts (m)	Damage to casuarina / palm / coconut trees (m)
Uroor Alcott Kuppam, Chennai	100	35 – 39	0
Vada Nemelli	-	0	13 - 25
Mahabalipuram	145	25 (wall)	0
Periyakalpet	65	23 - 33	0
Devanapatnam	65	27	0
Nanjalingampettai	135	0	10 - 17
- Poompuhar, north	100	44 - 56	0
- Near temple	-	10	0
Vanagiri	-	19	-
Tarangambadi	55	33 - 69	0
- Karaikal, north	180	>200 (sea wall)	0
- south	-	-	~15
Nagore	-	132	0
Silladi	120	0	7 - 19
Samanthanpettai	145	9 - 51	5
Nambiar Nagar	-	6	0
Nagapattinam lighthouse	-	30	0
Akkaraipettai - Keechankuppam	-	45 - 63	-
Kallar	-	45	0
Velankanni	100	75	-

Fig. 1.

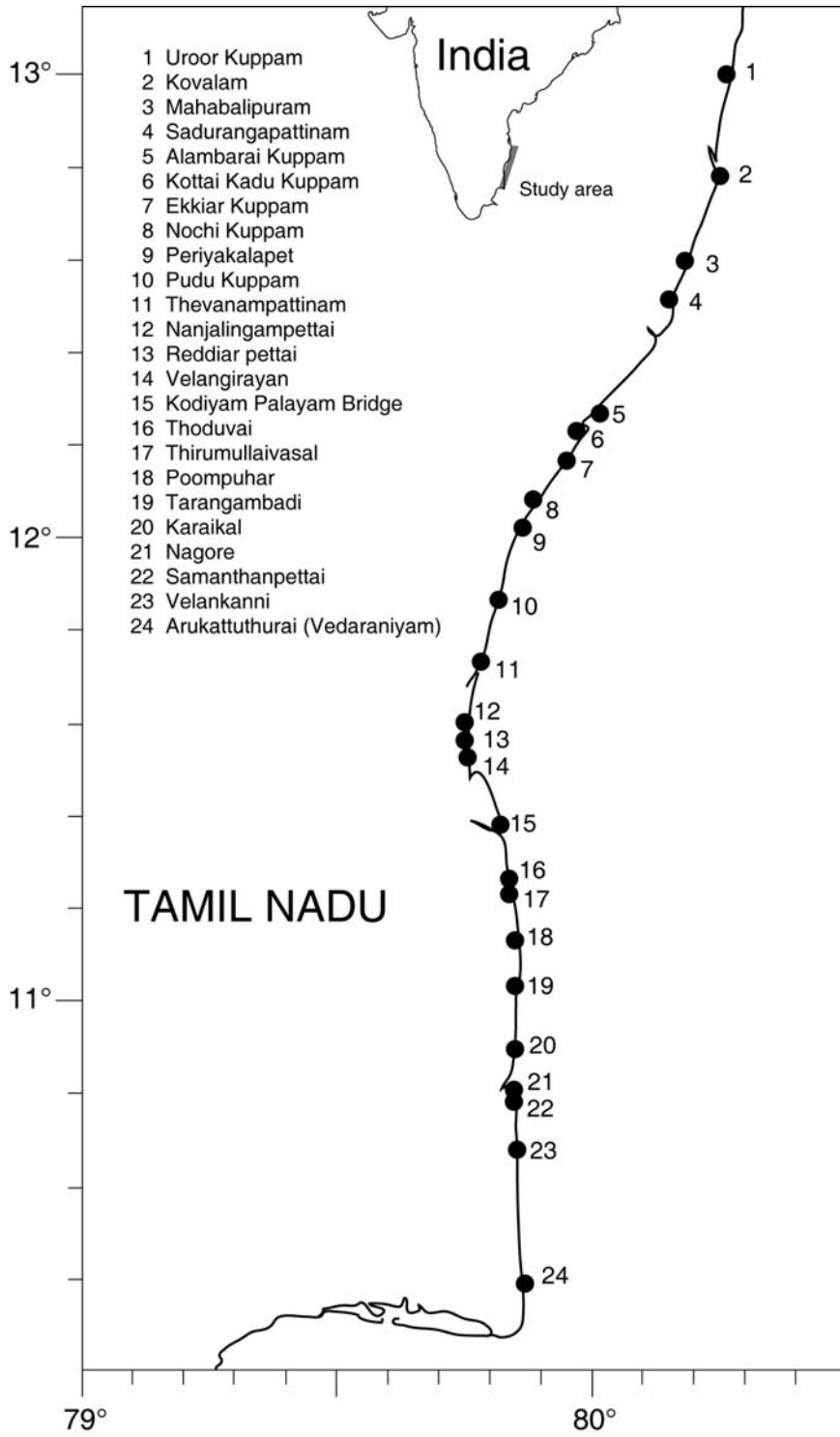


Fig. 2.

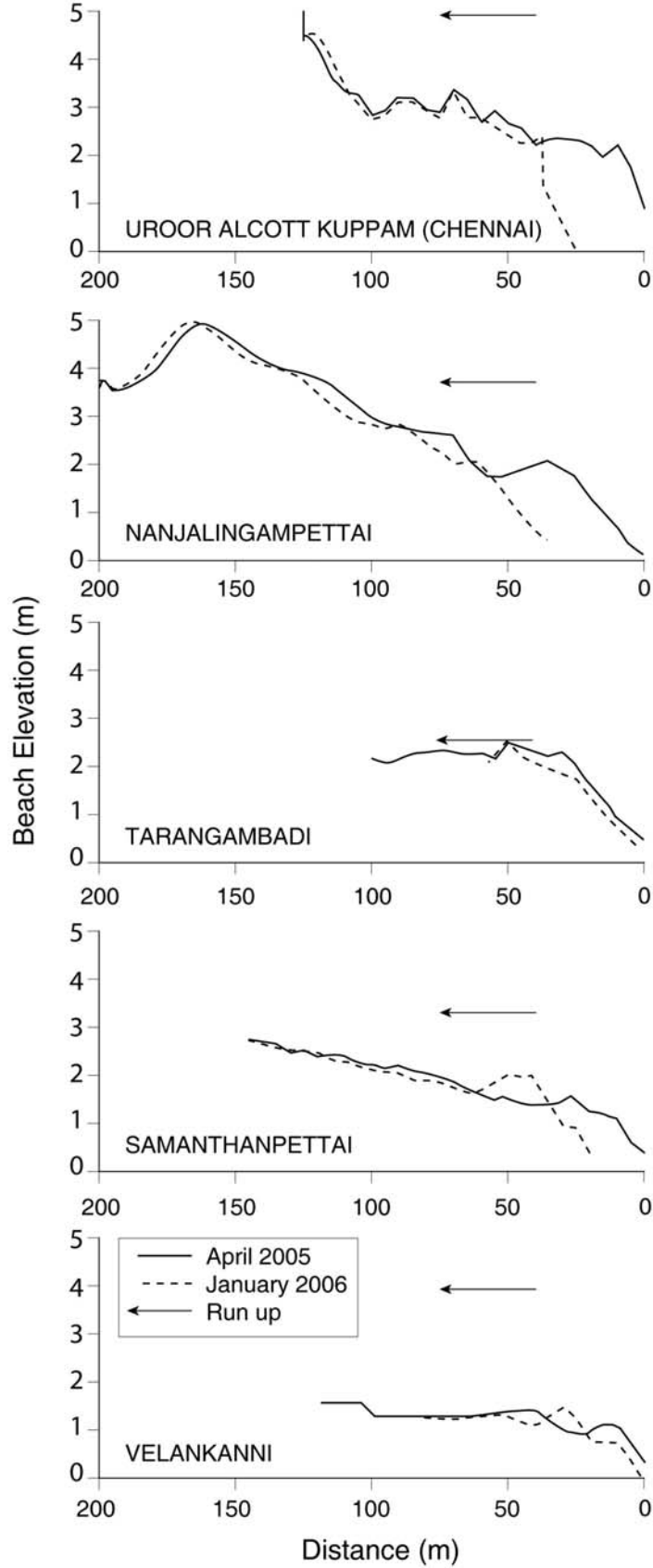


Fig. 3.

