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International Strategy for Disaster Reduction

Risk Factors for Mortality and Injury :

Post-Tsunami Epidemiological Findings from Tamil Nadu

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The Centre for Research on the Epidemiology of Disasters (CRED) is based at the Catholic University of Louvain (UCL), Brussels. CRED promotes research, training and information dissemination on international disasters, with a special focus on public health, epidemiology and social-economic factors. It aims to enhance the effectiveness of developing countries response to, and management of, disasters. It works closely with non-governmental and multilateral agencies and universities throughout the world.

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Table of Contents

List of Tables and Figures

Tables

Figures

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Executive Summary

The Indian Ocean tsunami of 26 December 2004 was a disaster of unprecedented dimensions causing the deaths of over 220,000 people in 12 countries. In the worst affected region of Indonesia, the death toll was more than 165,000 while in India the disaster affected over 2,000 kilometres of coastline and claimed over 16,000 lives. International attention has now been turned to how and why this disaster could have caused such an enormous loss of human life, leading to enquiries into what preventative methods might mitigate the effects of such disasters in the future.

Recognising the urgency to develop an early warning system for the Indian Ocean region, a multi-partner initiative "Evaluation and Strengthening of Early Warning Systems in countries affected by the 26 December 2004 Tsunami" was launched in 2005 and funded through the UN Flash Appeal for the Indian Ocean Earthquake-Tsunami. This UN/ISDR coordinated initiative has provided an overall integrated framework for strengthening early warning systems and building resilience of communities to disasters in the Indian Ocean. A major component of this initiative has been the assessment of community-based approaches in disaster mitigation and preparedness and the identification of vulnerability assessment methods in order to strengthen community response capabilities and informs policy makers of necessary measurements to be undertaken in that respect.

The current study was initiated to identify specific risk factors for mortality and injury with the aim of strengthening the current evidence base on disaster impacts and vulnerabilities. In October 2005, research teams from the Centre for Research on the Epidemiology of Disasters (CRED) and the University of Delhi worked in conjunction with the Tamil Nadu Voluntary Health Association (TNVHA) to conduct a major household survey and focus group sessions in Tamil Nadu, India.

A sample of 660 households was randomly selected from the most severely-affected hamlets in Nagapattinam District. A questionnaire designed to investigate possible risk factors at both the household and individual level was subsequently administered. Data from 651 households and 3131 individuals was collected and validated for statistical analyses. In addition to the survey data, four focus group discussions were held with men and women from fishing families, doctors and representatives from non-governmental organisations.

Just over one quarter of the surveyed population were injured on the day of the tsunami. Most injuries occurred on the extremities, with abrasions and lacerations reported as the most common injury-type. As expected, the vast majority of deaths and injuries occurred on the day of the tsunami. Young children and the elderly had much higher risk of death than the rest of the population. Results confirmed that women were at significantly higher risk of mortality than men however upon closer analyses this gender difference was only relevant for women between 15 and 50 years of age. By contrast, while adult men were more likely to survive, they were at much higher risk of injury. Amongst children and elderly people, the death rates for males and females did not differ significantly.

Another key risk factor for tsunami deaths was the inability to swim; a characteristic that was also strongly correlated with gender as significantly fewer females were able to swim than males. Furthermore, while people from households involved in the fishing industry were significantly affected by the disaster, the risk of mortality was more strongly correlated with a dwelling's proximity to the sea than with the household occupation type. Finally, while the survey revealed that a formal early warning system did not exist, approximately 13% of the surveyed population received a verbal warning from family or friends in the area. Death rates were significantly lower amongst the population that was warned, suggesting that regardless of their location at the time of the tsunami, receiving an early warning may have saved lives.

The results suggest that the vulnerability of coastal populations could be reduced in a number of ways. Promoting and providing swimming lessons amongst women and girls is likely to reduce their risk in flooding disasters. While the relocation of entire fishing communities away from the coast may not be feasible, improvements in local housing and other infrastructure could strengthen the resiliency of such populations in the future, as could the investment in multi-purpose emergency shelters. Early warning systems are likely to be beneficial however careful consideration of message dissemination methods is required to ensure their effectiveness and should be developed in conjunction with community disaster preparedness and awareness programs.

Finally, while a sound evidence base for mortality and injury risk factors is crucial for informing policy decisions and developing effective disaster preparedness and response systems, further studies aimed at strengthening the epidemiological data on acute disasters is required.

1. Introduction

Since the disastrous Indian Ocean earthquake and tsunami of 26th December 2004, questions have been raised on how such an event could have caused so much damage and loss of human life. Attention has thus been turned to how the international community, in conjunction with national and local governments, can work together to devise more effective early-warning systems and evidence-based policy changes in order to reduce the human impact of future disasters.

It is commonly acknowledged that deaths and injuries from disasters do not occur in a random manner. Understanding why one person died compared to another that did not, given similar exposure, provides the evidence base for targeted and effective disaster preparedness. The current study, *Risk Factors for Mortality and Injury: Post-tsunami Epidemiological Findings from Tamil Nadu*, aimed to identify the specific risk factors for mortality and injury as a result of the 2004 tsunami. By identifying such risk factors, the overall goals of this study were to contribute to:

1. Increasing the effectiveness of preparedness and response to tsunami early warning systems in the Indian Ocean Region;
2. Developing a scientific evidence-base on impacts and vulnerabilities linked to the tsunami in Tamil Nadu; and,
3. Learning lessons that will reduce mortality and morbidity from major natural disasters in the future.

The UN/ISDR coordinated initiative "Evaluation and Strengthening of Early Warning Systems in countries affected by the 26 December 2004 Tsunami" was launched in 2005 and funded through the UN Flash Appeal for Indian Ocean Earthquake-Tsunami, provided the necessary resources and mechanisms to undertake this study. The study has been jointly-conducted by the Centre for Research on the Epidemiology of Disasters (CRED) and the University of Delhi, with logistical and administrative support provided by the Tamil Nadu Voluntary Health Association of India (TNVHA). The current study follows earlier research conducted by CRED on the impact of the tsunami in terms of diseases in Aceh (4).

2. Background

The Indian Ocean earthquake (measuring 9.3 on the Richter scale) and tsunami which struck off the coast of Sumatra, Indonesia on the 26th of December 2004 was an unprecedented disaster in terms of the size and scope of its impact. Close to two million people in 12 countries were affected with over 220,000 dead or missing and hundreds of thousands of people injured.

Of the affected countries, the highest death toll was recorded in Indonesia, with an estimated 165,708 killed. Sri Lanka and India suffered the second and third highest death tolls, with approximately 35,399 and 16,389 deaths respectively (see Table 1 for a summary of the human impact across the tsunami-affected countries).

Box 1. Tsunami facts

Triggered by submarine earthquakes, landslides or volcanic eruptions, tsunamis are a series of ocean waves of considerable length and period that are able to travel large distances at speeds of up to 500 km/h, with little loss of energy.

Whilst a tsunami may be almost imperceptible as it travels through deep ocean water, on approaching shallower coastal waters the waves become compressed and slow down, leading to sudden increase in wave height. Following the main wave, successive crests (arriving at intervals of between10 and 45 minutes) may batter coastlines for several hours and cause widespread devastation (1) . Compared to data of such events over the last century, no other tsunami had claimed as many lives as the 2004 Indian Ocean disaster (3).

Table 1. Human impact of the 26 December 2004 earthquake and tsunami as of February 2006 (3)

Country	Killed	Affected*
Indonesia	165,708	532,898
Sri Lanka	35,399	516,130
India	16,389	647,599
Thailand	8,345	58,550
Somalia	298	104,800
Maldives	102	12,000
Malaysia	80	5,063
Myanmar	71	12,500
Tanzania	10	-
Seychelles	3	4,760
Bangladesh	2	-
Kenya	1	-
Total	226,408	1,894,300

* Including homeless

The disaster's high death toll can be attributed to the sheer magnitude of the event, as well as its timing. As has been reported for earthquakes, the timing of an acute catastrophic event can be a strong indicator of the human and material damage it can cause (5); earthquakes that occur at night for example, typically result in higher mortality than those that occur during the day. In this case, the Indian Ocean earthquake occurred at 7:59am, with the first tsunami hitting the Indonesian island of Simeule just minutes later. Being a Sunday, many locals and tourists were present on the beaches when the tsunami hit. Furthermore, with fishing being a major industry for many coastal communities surrounding the Indian Ocean, hundreds of people were out at sea or coming into shore with their mornings' catch. In India, where women are heavily involved in the fishing industry, many were reportedly waiting on the beaches for the fishermen to return when the tsunami hit (6).

In addition to the direct human impact, the tsunami had devastating consequences on urban infrastructure including water and sanitation systems, roads, schools and hospitals. In some locations, entire villages and local fishing industries were destroyed, along with essential health, education and emergency services (4).

Initially, makeshift camps of internally-displaced persons were without safe drinking water and food was in short supply. Despite being scientifically unfounded, the presence of large numbers of dead and decaying bodies led to fears of major disease outbreaks and triggered mass burials of unidentified corpses (7, 8).

2.1 The disaster in India

In India, the tsunami devastated over 2,000 kilometres of coastline along the southern Indian states of Tamil Nadu, Andhra Pradesh, Kerala, the Union Territories of Pondicherry, as well as the Andaman and Nicobar Islands. The tsunami, which hit Indian coastlines at around 9:50am, penetrated as far as three kilometres inland, affecting an estimated 3.6 million people, damaging approximately 14,827 hectares of cropped areas and causing financial losses of approximately 1.8 billion USD (9). According to government estimates in March 2005, 157,393 dwellings in 897 villages were damaged resulting in the evacuation of a total of 638,297 persons (10).

Across India, the disaster affected the livelihoods and shelters of the poorest sectors of the community, including fishermen, farmers, landless and casual labourers, small businesses and micro-enterprises (11). Notably, this group tends to contain a concentration of Most Backward, Backward, Scheduled Caste and Tribe members; typically the most disadvantaged groups in Indian communities.

Box 2. An Overview of Tamil Nadu

Located on the Indian peninsula, Tamil Nadu is India's southern most state surrounded by the states of Kerala, Karnataka and Andhra Pradesh and the Bay of Bengal on the east. Compared to other States, Tamil Nadu is one of India's more developed areas as reflected in its 2001 Human Development Index ranking of 0.657. As such, Tamil Nadu ranked higher than the HDI for the country as a whole (0.571) and placed third amongst India's 15 major States. At the time of the 2001 census, Tamil Nadu's population was recorded at approximately 62 million, with a population density of 478 persons per square kilometre. With 42 % of the population classified as living in urban areas, Tamil Nadu is India's most urbanised state (2). The official language of the state is Tamil, although other Dravidian languages including Telugu, Malayalam, and Kannada are also spoken by the population. The main religion in Tamil Nadu is Hinduism.

In terms of industry, agriculture represents the principle occupation followed by other industries including food processing, cotton and silk production. As in other regions affected by the 2004 tsunami, fishing families along the coast constituted a considerable proportion of Tamil Nadu's affected population.

2.1.1. Nagapattinam District, Tamil Nadu state

Of the mainland regions, Tamil Nadu state (Figure 1) bore the brunt of the tsunami with 7,983 deaths reported (figure current at June 2005, (11)). Amongst Tamil Nadu's 13 coastal districts, Nagapattinam (population 1.5 million) was the worst affected district recording a total of 6,065 bodies recovered in 58 hamlets; a toll which represents 75 percent of all the deaths in the state. In addition to the destruction of many Primary Health Centres, the Nagapattinam District Hospital was also affected by the tsunami flood waters which caused sewerage pipes to clog and damaged hospital equipment and supplies. As such, many seriously injured patients had to be transferred up to 150km away to Tanjavore Medical College and Hospital.

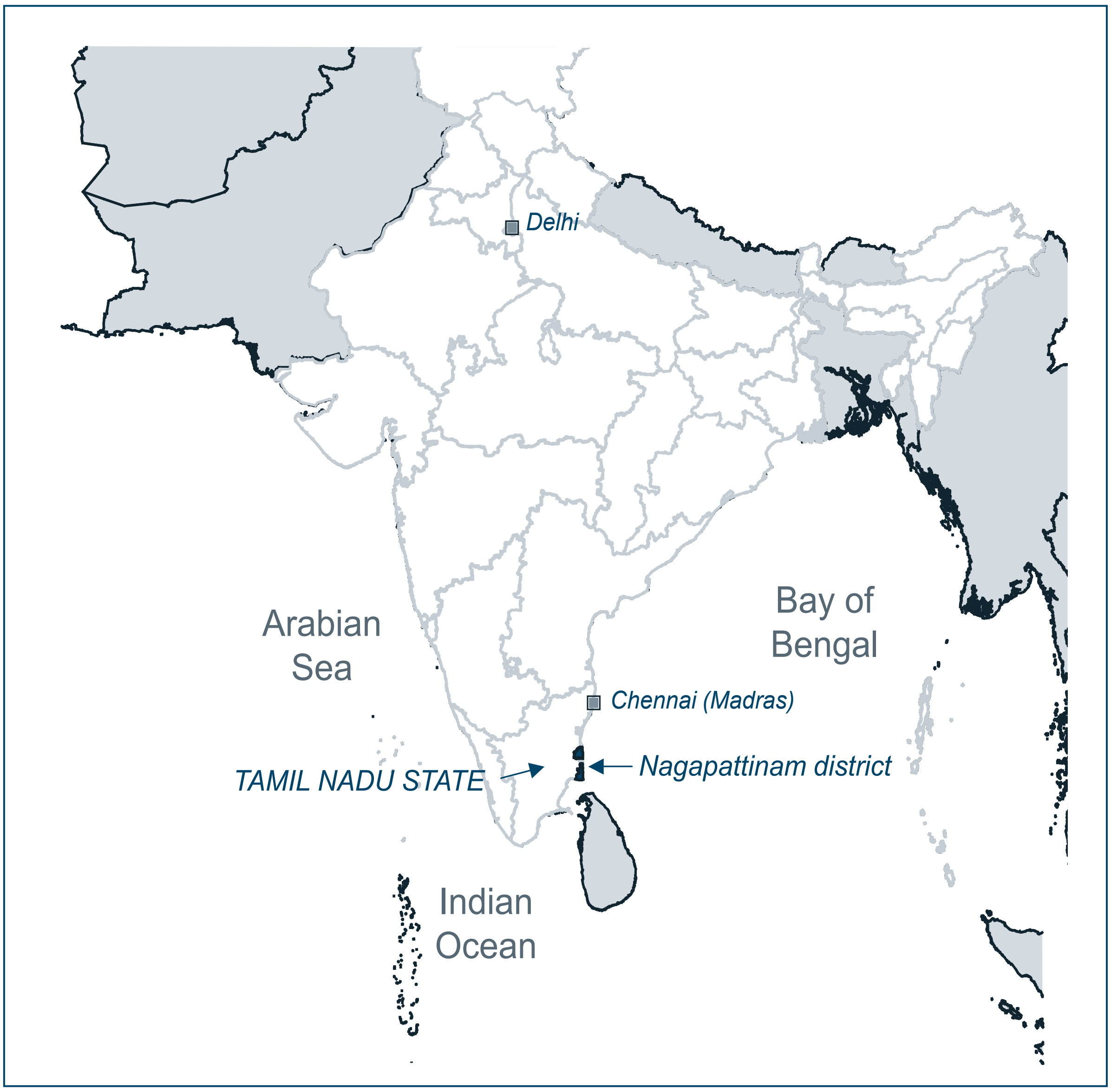

Figure 1. Location of Nagapattinam District, Tamil Nadu state

3. Effects and risk factors: A literature review

3.1 Health effects of tsunamis

The health impact of tsunamis may be quite complex. In the case of seismic tsunamis, the preceding earthquake may be powerful or close enough to shore (as was the case in Aceh) such that collapsing structures cause morbidity and mortality through lacerations, fractures and crush injuries. The subsequent tsunami presents new threats as people may be exposed to a range of so-called "flood actions" including extreme forces, pressures, motion, oxygen deprivation, chemical reactions due to contaminants, impact from debris and flood-related fire consequences (12). Receding tsunami waters can generate a strong suction of debris, leading to further injury and causing structural damage to buildings (13).

As displayed in Table 2, data collated on seismic tsunamis during the mid-1990s revealed that expected death to injury ratios may vary from 0.02 to 0.50 (14).

Table 2. Death to injury ratios of seismic tsunamis, 1994-1996 (14)

Tsunami profiles								
No.	**Date**	**Location**	**Local time**	**Magnitude**	**Deaths**	**Injuries**	**Deaths/ Injuries**	**Remarks**
1	19/01/94	Indonesia (Irian Jaya)	10h54	6.8	7	40	0.17	2m tsunami
2	02/06/94	Indonesia (E. Java)	3h17	7.2	222	440	0.50	Tsunami
3	04/10/94	Kuril Islands, N. Japan	22h23	8.2	11	422	0.02	1.5-3m tsunami
4	14/11/94	Philippines (Mindoro)	3h15	7.1	74	171	0.43	10-15m tsunami (1.5m min.)
5	14/05/95	Indonesia (East Timor)	19h33	6.8	6	26	0.23	Tsunami with landslides
6	09/01/96	N.E. Guatemala	16h25	4.6	0	9	-	2m tsunami
7	17/02/96	Indonesia (Irian Jaya)	14h59	7.0	108	423	0.26	2-4m tsunami

In the immediate aftermath of a tsunami, affected populations are vulnerable to a range of environmental hazards. The loss of shelter exposes people to insect bites, heat and contaminated water. Other health risks may include flood-related fires, explosions from gas leaks, downed live wires and falling debris. Water-borne diseases (including enterotoxigenic Escherichia coli, Shigella, hepatitis A, leptospirosis, giardiasis) represent serious health threats, as do vector-borne disease and infections (15). Food and medical supplies may be disrupted and, as for almost all natural disasters, increased levels of physical and emotional stress become evident (15, 16). Indeed mental health and psychosocial problems have been identified as a major concern amongst tsunami-affected communities (17). In addition to cases of heightened fear and anxiety over future tsunamis, post-traumatic symptoms, depression and alcoholism, the widespread destruction of crops and livelihoods and delayed reconstruction of permanent housing have likely impeded the psychosocial recovery of affected populations.

3.1.1 Mortality

In terms of mortality, the vast majority of tsunami-related deaths tend to be due to drowning (13). In the case of the 2004 Indian Ocean tsunami, the large proportion of deaths compared to injuries suggests that those who suffered fractures due to collapsing structures or impact forces during the wave lost their capacity to swim and therefore drowned upon immersion (18, 19). In addition, many people who survived the tsunami itself died later as a result of near-drowning respiratory complications associated with the ingestion and inhalation of water (18). Myocardial infarctions or cardiac arrest also present an increased risk of death as they tend to be triggered by extreme stress and overexertion both during and after disasters such as the tsunami (16). Numerous reports indicated that across the tsunami region, women died in disproportionately greater numbers than men (20).

3.1.2 Trauma injuries

As mentioned above, traumatic injuries and soft tissue infections were exhibited by large proportions of the population affected by the Indian Ocean tsunami (21). Like other flood disasters, injury patterns were concentrated in the first few weeks following the tsunami. Common injuries included contusions, open wounds, fractures and head injuries as a result of people being swept away in the water and thrown against stationary objects or hit by floating debris (4). In some cases, compression barotraumas of the tympanic membrane were detected as a result of pressure from turbulent water (19).

Reports from Thailand suggested that tsunami wounds demonstrated specific characteristics, namely, small-to-medium multiple injuries occurring along the head, face and extremities and very often on the posterior side of the head, back, buttocks and legs (22). In addition to impact wounds which occurred during the tsunami, post-tsunami research conducted in Aceh revealed that many injuries were also caused by contact with broken glass and other debris as people returned to the affected areas in clean-up efforts (4).

Complicating the treatment of tsunami survivors were the unhygienic conditions which, like other post-disaster situations, increased the vulnerability of open wounds to infection. Many survivors who had experienced near-drowning events had “remained in unclean and traumatic conditions without receiving any immediate medical care for several hours” (23) (p. 1592). Immersed in stagnant and tepid water, open wounds and fractures provided ideal conditions for different strains of bacteria, fungi and amoebae to spread (23). In some cases, tetanus developed as a serious complicating factor for injured patients who required treatment with intravenous doses of tetanus immunoglobulin (24).

In many cases, wound contamination with soil, seawater or sewerage precipitated a range of infections from superficial skin infections to serious cases of fasciitis (muscle membrane infection), myositis (muscle infections) and osteomyelitis (bone infections) as well as systemic diseases including meliodiosis or sepsis (4). In fact the combination of a large number of rare environmental pathogens that result from severe trauma, extensive soft tissue and internal injuries, the presence of multi-drug resistant bacteria, atypical bacteria and fungal infections and limited medical resources, all contributed to the difficulty of post-tsunami treatment (23). In this regard, the presence of unusual or resistant pathogens has been identified as a specific risk requiring greater attention in terms of future disaster preparedness and emergency treatments (4).

3.1.3 Respiratory infections

Acute respiratory infections are often recognised as one of the most common health conditions to increase during disaster situations. In fact studies of hospital records in Aceh demonstrated that close to 90 percent of a typical annual caseload occurred during the first few months after the tsunami (4).

In the particular case of flooding disasters such as the tsunami, aspiration pneumonia (which is a bacterial infection of the lungs and can be caused by the inhalation of water) is a common consequence of near-drowning[1]. In the case of the tsunami, many people who had had near-drowning experiences inhaled saltwater contaminated with mud and bacteria, resulting in a type of necrotising aspiration pneumonia which came to be dubbed “tsunami lung”. If left untreated, the resulting infection often spread into the bloodstream and brain, resulting in abscesses and serious neurological problems, including paralysis (25). In Aceh, patients with necrotising pneumonia symptoms continued to present at the hospital up to one month after the tsunami. Treatment with broad spectrum antibiotics was often ineffective, resulting in the use of carbapenems as the main antibiotic for post-immersion respiratory infections in Banda Aceh (26).

It should be noted that in addition to the presence of highly resistant bacteria requiring complex and aggressive antibiotic treatment, the post-tsunami response to respiratory infections was challenged by the lack of medical experience in dealing with near-drowning complications due to the rarity of such events (23).

3.1.4 Communicable diseases

Following flooding disasters such as the tsunami, communicable diseases including tetanus, dysentery, malaria and dengue may pose a heightened risk to surviving populations. Except under conditions of poor sanitation and crowding which may occur in the context of large displacement camps, the risk of water-borne epidemics of cholera or shigella dysentry for example, tends to be rather low.

In the case of the Indian Ocean tsunami, no major disease outbreaks or epidemics occurred in any of the affected regions. This was partly due to effective and coordinated public health responses (such as the rapid distribution of bottled water supplies) aimed at mitigating such threats (4, 7) as well as specific environmental conditions which may have inhibited the proliferation of certain diseases. Specifically, these conditions included water temperatures reported to be unfavourable to the transmission of cholera and the salination of fresh water pools which, at least initially, reduced the number of potential mosquito breeding grounds thereby mitigating the risk of mosquito-borne diseases such as malaria and dengue.

[1] Near-drowning incidents tend to be defined as survival after suffocation caused by submersion in a liquid.

3.2 Risk factors for mortality and injury

A better understanding of the risk factors for mortality and injury as a result of the tsunami is required in order to improve preparedness and mitigate the effects of such disasters in the future. Risk in this regard, may be considered as a product of hazard factors and vulnerability factors, whereby hazard factors include aspects such as water depth, velocity and temperature, as well as the quantity and nature of floating debris and contaminants, and vulnerability relates to individual factors such as age, gender, physical and mental health history, physical and mental condition at the time of the disaster, activity and behaviour (for example, attempting a rescue, sleeping or evacuating), clothing worn, swimming ability and experience, temporary impairment (that is, drug or alcohol intoxication), knowledge of the area where the flood is occurring, the situation and location of the individual, and rescue and medical response capabilities (12, 27, 28).

A review of the literature reveals a number of vulnerability factors which may place individuals at greater risk of death and injury during natural disasters such as the tsunami, for example, age (both the very young and old tend to be at greater risk in such conditions), gender (depending on the conditions, being male or female is a risk factor), a lack of warning or preparedness and distance to the sea (the closer one's dwelling is to the coast, the greater the risk). Studies of earthquake risk factors have also identified those living alone as being of higher risk of death (5).

3.2.1 Young children and the elderly

The dependency of young children and babies underlies their vulnerability during natural disasters. In disasters such as the tsunami, young children and babies lack the developmental capacity or strength to escape the hazard. In fact numerous reports of different natural disasters have demonstrated this age-related vulnerability[2]. Elderly people, in addition to their weaker physical strength and resilience, may experience difficulties in receiving, interpreting and acting on disaster warnings and may be more vulnerable to heart attacks under stressful conditions (12, 30).

3.2.2 Gender

According to the literature, males or females may be more at risk during different natural disasters, for different reasons. Jonkman and Kelman (12) for example report that during flood disasters males are "significantly overrepresented in vehicle crashes, drowning and physical trauma, and in cases of pedestrian drowning" (p. 87). Likely contributing factors are the large number of males who drive, the high proportion of males who work for the emergency and supporting services, and the tendency for males to engage in risk-taking behaviour (12).

However the vulnerability of the genders appears to differ across countries. For instance, significantly more women than men lost their lives in the 1991 Bangladesh cyclone (29). This was associated with factors such as women's social roles, their style of clothing, their lower physical strength and poorer levels of nutrition (12).

[2] In studies of the 1991 Bangladesh cyclone for example, children and the elderly died disproportionately more than others in the population, with almost 75 percent of deaths being of children under 15 years of age. (29). Chowdhury AMR, Bhuyia AU, Choudhury AY, Sen R. The Bangladesh Cyclone of 1991 - Why So Many People Died. Disasters 1993;17(4):291-304.

Similarly, following the 2004 tsunami, women appeared to be at greater risk of tsunami mortality than men. An Oxfam survey carried out in tsunami-affected regions of Indonesia, Sri Lanka and India found that in some areas women were up to four times as likely as men to be killed (6). This was partly explained by the fact that in general, women in these countries died because they stayed behind to look after their children and other relatives, and most women in these areas were unable to swim or climb trees to save themselves. However there were also different socio-economic and cultural reasons for the disproportionate deaths of women across these regions. In the case of India, women tend to assist in the fishing industry, which meant that at the time of the tsunami, many women had been waiting on the shore for the fishermen to return (20).

3.2.3 Ability to swim

The lack of swimming ability has, as previously mentioned, been suggested as a factor underlying the higher death tolls amongst women during the 2004 tsunami (6). However, while Jonkman and Kelman (12) recognise swimming ability and experience as a potential characteristic that might mediate individual vulnerability in the case of a flooding disaster, they qualify that this is likely only to be relevant in still water conditions.

3.2.4 Distance to the sea

Coastal populations are particularly vulnerable to the hazards presented by tsunamis, cyclones and storm surges[3]. Tsunami vulnerability is related to a combination of factors including, among others, the presence of on and off-shore barriers, depth of the flood water, and the ability of the population to evacuate the flood zone (32). Therefore, while it is generally accepted that distance from the shore is an important factor to consider, the risk to population and infrastructure varies across a tsunami flood zone.

3.2.5 Socio-economic status and housing construction

According to Guha-Sapir (33), numerous studies have found that higher mortality rates from natural disasters tend to occur in areas with the lowest socioeconomic conditions. The literature on earthquake risk factors suggests that individuals with lower socio-economic status may be more at risk of dying due to their greater exposure to environmental risk factors such as poor housing. Even when controlling for demographic, health and area characteristics, the risk of earthquake death increased with decreasing monthly wage (30).

Many houses and buildings along the coastal communities of the tsunami-affected countries were poorly constructed. Poor construction compounds the threat of natural hazards, as their failure to withstand extreme wind and/or water forces raises the risk of injury and mortality for inhabitants. In post-cyclone studies in Bangladesh for example, death rates varied by the type of pre-cyclone housing, with the greatest death rates occurring for kutcha houses with tin roofs, followed by kutcha houses with thatched roofs. The death rate was low for pucca houses, while double-storied houses recorded no deaths (29).

[3] In India, where approximately one quarter of the population resides within 50km of the coast, with thousands of seafaring and fishing communities nestled only a few hundred metres from the shore, the implementation of coastal zoning and relocation has become a major issue in post-tsunami reconstruction plans. (31). Krishna KS. Science plan for coastal hazard preparedness. Current Science 2005;89(8):1339-1347.

Post-tsunami research in Thailand and Indonesia revealed that common building material for residential houses included wood frames and roofing made of clay tiles or thin corrugated steel sheets, which survived the earthquake but were obliterated during the tsunami. Other buildings consisted of non-engineered concrete frame structures with masonry infill. Most of these building also suffered extreme damage or collapsed completely, while buildings made of engineered reinforced concrete suffered the least damage (34).

Not only may poor construction lead to increased risk of injuries due directly to collapsing structures, it was noted that following the tsunami, "most of the observed debris left by the receding water was from this type [residential wood houses with tile of corrugated steel sheet roof] of housing construction, in addition to cars boats and parts of trees" (34) (p. 315). According to Ghobarah, et al. (34) this debris blocked roads and significantly impeded search and rescue efforts.

3.2.6 Preparation, warning and evacuation

Most lethal flood disasters tend to be those that hit with little warning, such as flash floods and storm surges (12). Like other quick-onset disasters, tsunamis may leave little time for preparedness or evacuation, thereby raising the risk of mortality and injury. In the case of the Indian Ocean tsunami, affected regions received little, if any, prior warning of the tsunami and therefore had no time to prepare or evacuate. This has been commonly identified as a contributing factor to the disaster's heavy death toll (35).

One way to mitigate the impact of sudden impact disasters is to ensure disaster and emergency health services are well prepared for such an event. Unfortunately prior to the 2004 tsunami, the health care systems of many of the affected countries were already suffering from a shortfall in human and material resources and infrastructure (36). This vulnerability was compounded by the fact that local health infrastructures were badly damaged during the disaster and state and national health services were ill-prepared to manage such a large number of casualties (37).

3.3 Methods for reducing mortality and morbidity

The lessons learned from past disasters have led to methods for reducing the vulnerability of populations to such threats. For example, earthquake and cyclone-resistant building codes have been developed and are compulsory in many developed countries. Unfortunately, well-engineered dwellings, let alone those built to cyclone or earthquake codes tend to be rare in communities of poor developing countries. In recognition of population vulnerabilities, some governments and NGOs have invested, for example, in the construction of multipurpose cyclone shelters. The benefits of these constructions have been demonstrated. For example, following a severe cyclone in Bangladesh in 1991, researchers found that compared to the total population, death rates were doubled for the population that did not seek refuge in a cyclone shelter. Calculations of the number of deaths averted by formal shelters found that without the formal shelters, at least 20 percent more deaths would have occurred (29). In disasters such as tsunamis, or cyclone-related storm surges, the construction of embankments along the coast has also been shown to provide some protection from encroaching waters (29).

Warnings have often been cited as a means through which to reduce the human impact of natural disasters. However the effectiveness of the warning system relies on a number of factors, including a well established local communication network, people's understanding of how to react to such warnings, as well as local beliefs and perspectives.

4. Methodology

Compiling a profile of high risk individuals and identifying why certain characteristics lead to higher risk of mortality and injury facilitates the design of effective preparedness and responses strategies.

The current study used two information sources for its analyses: household surveys and focus groups. A structured household survey was conducted to obtain quantitative data for statistical analyses while the focus group discussions complemented the survey findings with qualitative information. Additional contextual information relevant to the study was gathered from local authorities.

4.1 Household survey

As one of the most severely affected regions, Tamil Nadu state in southern India was identified as an appropriate research location for the current study. Nagapattinam District was in turn selected as the specific site for the field mission in that it recorded 75 percent (i.e. 6,065 bodies retrieved) of all the deaths in the state.

The study sample focussed on hamlets defined by the Government of India as the most severely affected; namely those that had recorded 50 or more deaths (bodies retrieved) due to the tsunami. This criterion also ensured that the sample would contain sufficient mortality data for subsequent analysis.

The sampling universe therefore comprised Nagapattinam District's 25 most severely-affected hamlets (see Table 3), the locations of which are displayed in Figure 2. According to 2001 Census data, the total pre-tsunami population of these hamlets was 59,750, of which the Government recorded 5,613 deaths (9.4%) as a result of the tsunami.

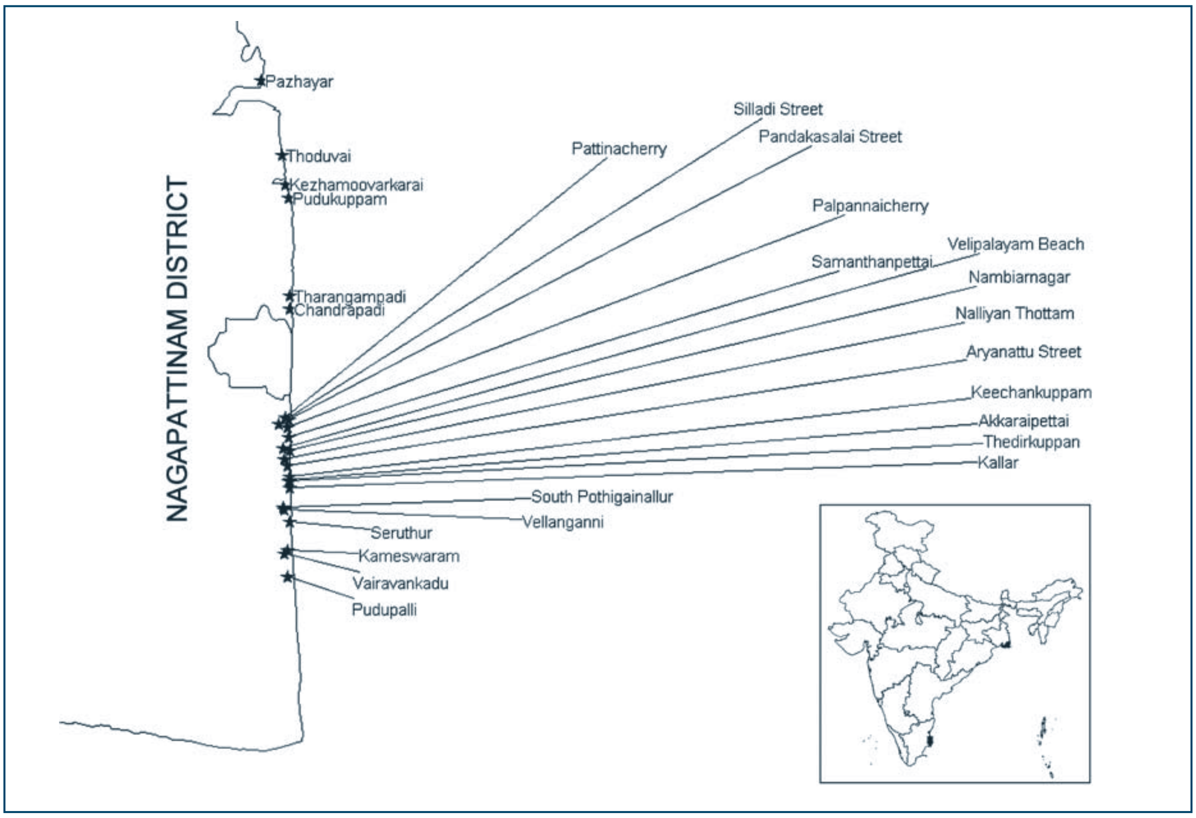

Figure 2. Location of hamlets included in the survey

Table 3. Hamlets included in the survey

Severely affected hamlets, Nagapattinam District				
Kallar	Velipalayam Bch.	Samanthanpettai	Seruthur	Pudukuppam
Akkaraipettai	Aryanatu Street	Silladi St.	Kameswaram	Kezhamoovarkarai
Keechankuppnam	Nalliyan Thottam	Pandakasali St.	Vairavankadu	Pazhayar
Thedirkuppam	Pattinacherry	Sth Pothigainallur	Pudupalli	Chandrapadi
Nambiamagar	Palpannaicherry	Vellanaganni	Koduvai	Tharangampadi

4.1.1 Sample selection

The sample size for the household survey was calculated based on the Fleiss formula. According to this formula, a sample size of 3,000 individuals would enable the detection of relative risks of at least 1.5, where exposure factors have a population prevalence of approximately 15% or more. Since analyses of factors with a lower population prevalence and relative risk were unnecessary for the current study, a sample size of 3,000 individuals was determined to be sufficient.

The 2001 census registered an average household size of 4.69 for the Nagapattinam District, however following consultation with local officials and taking into account the population profile (poorer socio-economic conditions, predominantly fishing and agricultural labour families) calculations were based

[4] This proved to be a close approximation of the survey sample, which revealed that the average household size at the time of the tsunami was 4.8.

on an average household size of 5[4]. Based on this figure, 600 households were required to generate a sample of 3,000 individuals. This household sample size was augmented by 10 percent in order to account for possible missing households or a possible lower-than-average household size, resulting in the final sample size target of 660 households.

The selection was conducted with a simple random sampling method. Based on population data of the affected villages at the time of the tsunami, a list of all households within the 25 selected hamlets was compiled. This resulted in a total of 20,265 households to which a unique identification number was individually assigned. Subsequently, a computer-generated sample of 660 numbers was obtained from which the matching households were identified for inclusion in the survey. Table 4 shows the number of households that were selected in each hamlet.

Table 4. The number of households selected from each survey hamlet

	Total number of households	(%)	Selected households	(%)
Akkarapettai	1349	6,7%	43	6,5%
Aryanattu Street	845	4,2%	25	3,8%
Chandarapadi	491	2,4%	16	2,4%
Kallar	247	1,2%	9	1,4%
Kameshwaram	1149	5,7%	35	5,3%
Keechankuppam	875	4,3%	23	3,5%
Kezhamoovarkarai	469	2,3%	13	2,0%
Nalliyan Thottam	543	2,7%	20	3,0%
Nambiyar Nagar	1386	6,8%	45	6,8%
Palpannaicherry	101	0,5%	2	0,3%
Pandakasalai Street	161	0,8%	5	0,8%
Pattinacheri	744	3,7%	19	2,9%
Pazhayar	2530	12,5%	107	16,2%
Pudukuppam	162	0,8%	2	0,3%
Pudupalli	733	3,6%	23	3,5%
Samanthanpettai	277	1,4%	11	1,7%
Seruthur	786	3,9%	26	3,9%
Silladi Street	350	1,7%	10	1,5%
South Poipaikainallur	1190	5,9%	29	4,4%
Tharangampadi	1116	5,5%	34	5,2%
Thedirkuppam	381	1,9%	13	2,0%
Thoduvai	836	4,1%	33	5,0%
Vairavankadu	280	1,4%	8	1,2%
Velipalayam Beach	570	2,8%	18	2,7%
Vellanganni	2694	13,3%	91	13,8%
	20265	100,0%	660	100,0%

4.1.2 Survey questionnaire

A questionnaire was developed in consultation with the Department of Anthropology of the University of Delhi and the TNVHA. The questionnaire was designed to collect information that allowed analyses of both household and individual characteristics in relation to mortality or injuries sustained due to the tsunami. The entire form was translated from English to Tamil by TNVHA staff.

An electronic version of the questionnaire was created in EpiInfo 6 for DOS (Centers for Disease Control, Atlanta, USA). Options were entered and quality checks were encoded in order to facilitate the validation. The first part of the survey tool included questions aimed at determining household characteristics at the time of the tsunami. These included caste status, the material from which the dwelling had been constructed, distance of the dwelling from the sea and household access to communication technology (televisions, radios and mobile phones).

The second part of the questionnaire focussed on gathering data on individual risk factors. The questionnaire was constructed such that one representative from the household was interviewed on every individual that had been living as a member of their household on the day of the tsunami. Questions aimed at gathering information on individual characteristics such as age, gender, education, location at time of tsunami, ability to swim, rescue efforts, presence or absence of warning and survival/ escape mechanisms, as well as information on any cases of injury or death that occurred on the day of the tsunami and up to one month after the disaster. It should be noted that data on self-reported illness was not collected during the survey due to the likely effects of recall bias.

In order to ensure the cultural sensitivity and appropriateness of the questionnaire, the phrasing of all questions and terminology used was verified by experts and local personnel. Once the questionnaire had been finalised and translated, a three day pre-test was conducted in hamlets not included in the survey list in order to identify potential comprehension problems and to make appropriate modifications to the questionnaire prior to the training day and actual survey period. As a result of the pre-test, only a few minor changes to the questionnaire were required.

The possibility of conducting a back-translation of the questionnaire was discussed however in light of time constraints and considering that the person conducting the translation into Tamil had been heavily involved in the preparatory meetings and had a good understanding of the meaning and intention of the questions, this option was not pursued. It is acknowledged however that if conditions permit, a back-translation of survey tools can be of value.

4.1.3 Training

The household survey was conducted approximately 10 months after the tsunami by 32 (17 male and 15 female) Tamil-speaking investigators recruited from TNVHA, other NGOs and post-graduate institutions.

Figure 3. Investigators in training

Prior to the survey period, a training day (Figure 3) was conducted to ensure the investigators understood the questions in the survey and how to code the responses. The training began with an explanation of the context and purpose for the study followed by a detailed explanation of each question. Investigators were provided with the opportunity to pose questions and seek clarifications before being divided into pairs for practice sessions. At the end of the theoretical training, all investigators were dispatched for a training interview with households in the surrounding (non-survey) village. This enabled investigators to become familiar with obtaining informed consent and conducting interviews in a realistic setting. Once the investigators had completed their field practice, a final question and answer session was conducted by the training coordinators and the survey materials and schedule distributed to each of the investigators.

4.1.4 Implementation of survey

Each investigator surveyed approximately five or six households per day up to a period of five days (from the 4th to the 8th November, inclusively). Due to poor weather conditions that occurred during the surveying period, four households became inaccessible due to rising floodwaters and could not be interviewed. In total, the results from 656 households were collected.

On making verbal contact with the first respondents in the household, the interviewers introduced themselves and explained the objectives of the study. Verbal informed consent was obtained from all respondents before the start of the interview. It was emphasised that interviewees had the right to end their participation in the questionnaire at any moment.

Each respondent was asked questions about the household and every household member starting with him/herself. If the respondent stated that a household member was not living in the household at the time of the tsunami, the interviewer moved on to the next household member.

4.1.5 Data entry

The data was subsequently entered using EpiInfo 6 for DOS by staff from CRED and the University of Delhi. For almost all questionnaires this was done on the same or the next day. Data entry was conducted by four people on three computers. Upon completion of the data entry, inputs were merged into a single data file.

4.1.6 Data validation

A first stage of data validation occurred in the field. This manual validation targeted possible recording errors. During data entry, questionnaires that contained potentially erroneous fields were examined. If necessary, households were re-visited in order to verify or complete the questionnaire as required.

A second level of validation was incorporated in the EpiInfo software. The software enabled the integration of quality checks to minimize data entry errors. As such, any entry that did not confer with a predefined list of valid possibilities was rejected.

Upon completion of the field mission, a final validation for completeness and coherence was performed through ad hoc programs performing range and consistency checks. Inconsistent data entries were manually verified and corrected.

4.1.7 Data analysis

Data analysis utilised several software packages. Logistic regressions, charts and cross tabulations were conducted with SPSS 13.0 for Windows. EpiInfo 3.3 for Windows was used for calculation of relative risks and Microsoft Excel 2003 for additional tables and charts.

4.2 Focus Groups

Four focus groups involving 1) fishermen 2) women from fishing families 3) NGO representatives and 4) local medical personnel were conducted between the 5th and 8th of November 2006. All of the focus groups were held in Nagapattinam District and consisted of between seven and twelve participants (see Table 5). The focus group discussions were directed by the Field Team leader, who was assisted by a Tamil-speaking co-investigator, with the aid of local translators where required. The aim of these focus groups was to obtain additional information on risk factors for mortality and injury which would complement the survey data.

Table 5. Focus group profiles

Group Type	Sex			Age			
	Male	Female	Total	21-30	31-40	41-50	>50
Fishermen	12	-	12	1	8	3	0
Women	-	10	10	6	0	4	0
NGOs	6	1	7	1	2	3	1
Doctors	3	7	10	2	1	5	2

The focus groups with fishermen, women and NGO heads were conducted in a community hall away from the residential area. The participants were provided with transport to the venue and lunch. This was organised to ensure the participants' privacy and to ensure participants could remain focused on the discussion. The doctors' focus group was held at the office of the Deputy Director of Health Services. All the doctors involved in the focus group belonged to the Primary Health Care services and had worked for the Tsunami relief effort.

After welcoming and registering the participants for the focus group sessions, an explanation of the aims and purposes of the study was provided and participants were assured that all responses would be treated anonymously. The focus group rules and procedures were then explained to the participants who were asked to respond in turn to the focus group lead questions. Once all participants had spoken, a brief summary of the discussion was presented to stimulate additional comments and clarification. The discussions were recorded using audio and video tape recorders. For the men and women from fishing families, the focus groups were conducted in Tamil and the Tamil transcripts subsequently translated into English. Each Focus Group lasted between 2 and 2 ½ hours.

5. Results

5.1 Household survey

As previously mentioned, four of the 660 households could not be interviewed due to rising floodwaters. Of the 656 household questionnaires that were conducted, five had to be discarded later due to unreliable data which could not be validated, resulting in a final dataset comprising 651 households.

5.1.1 Characteristics of the sample

Information was collected at both the household (n= 651) and individual levels (n= 3202) (see Table 6 for an overview of sample characteristics). Analyses were only conducted on individuals who were members of the sampled households on the day of the tsunami. Those for whom this was not the case (n= 71) were thus excluded, leaving a final dataset of 3131 individuals.

Table 6. An overview of survey sample characteristics

Gender	(n)	(%)
Male	1547	49.4%
Female	1583	50.6%
Age		
Under 15 years old	963	30.8%
15-49 years old	1807	57.8%
50 years old and more	356	11.4%
Occupation		
Fishing industry	2313	73.9%
Agricultural labour	256	8.2%
Other occupation	552	17.6%
No employment	10	0.3%
Years of education		
Male		
0 years of education	418	27,0%
1-6 years	589	38,0%
More than 6 years	541	34,9%
Female		
0 years of education	665	42,0%
1-6 years	472	29,8%
More than 6 years	446	28,2%
Total		
0 years of education	1083	34,6%
1-6 years	1061	33,9%
More than 6 years	987	31,5%
Religion (Household level)		
Hindu	569	87.7%
Christians	57	8.8%
Muslims	23	3.5%

Caste (Household level)	(n)	(%)
Most Backward Caste	499	77,1%
Backward Caste	84	13.0%
Scheduled Tribe & Scheduled Caste	37	5.1%
Other	27	4.2%
Pregnant		
15-19 year old women	4	1.9%
20-24 years	18	10.6%
25-29 years	13	8.8%
30-34 years	5	4.8%
35-39 years	4	3.2%
15-49 years	*44*	*4.8%*
20-39 years	*40*	*7.3%*
Location at the time of the tsunami		
Was at sea or on the beach	642	20.6%
Was elsewhere	2474	79.4%
Swimming ability among +5 years old		
Male		
Could swim	884	64.2%
Could not swim	493	35.8%
Female		
Could swim	223	16.0%
Could not swim	1173	84.0%
Communication technology (household level)		
Radio	347	53.4%
Television	319	49.1%
Landline or mobile	79	12.4%
None	205	31.5%

Households ranged in size from single-occupant dwellings to households with up to 12 members, representing an average household size of 4.8 at the time of the tsunami. The vast majority of households were Hindu (87.4%), with Christian (8.8%) and Muslim (3.5%) faiths representing small minorities. According to the survey sample, close to 78% of severely-affected households belonged to the Most Backward Caste (MBC)[5] and almost three quarters of the surveyed households were identified as male-headed.

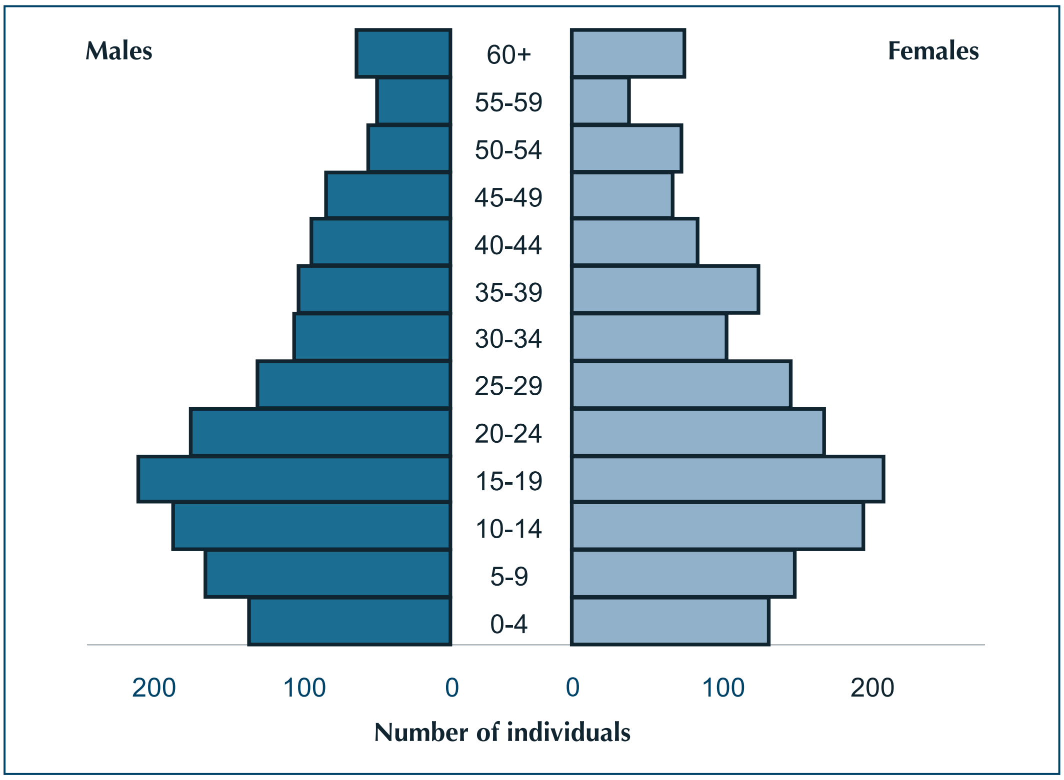

Figure 4. Population pyramid

The male to female ratio (0.977) of the surveyed sample was almost equal, with 1547 males and 1584 females (see Figure 4). Illiteracy amongst the surveyed population was at 39.3%, with women reporting significantly fewer years of education than men. Consistent with previous census data from Tamil Nadu, only 31% of the surveyed population was younger than 15 years of age.

Prior to the tsunami, the most common construction material used for houses in the hamlets surveyed was stone or brick (64.2%, n= 417). Approximately 25% of dwellings had been constructed from mud and coconut leaves and another 10% were built with concrete. As expected, fishing-related activities were the most common source of livelihood for the households surveyed, with 71.1% engaged in this sector at the time of the tsunami.

Regarding access to media and communications, the survey results revealed that the average household from severely-affected hamlets had either a functioning television, radio, or both. The majority of households (53.4%, n= 347) reported owning a radio, while slightly fewer households (49.1%, n= 319) had a functioning television at the time of the tsunami. In comparison only 12.4% (n= 79) of households had a functioning telephone or mobile phone and approximately one third (31.5%, n= 205) of households did not possess any of these means of communication.

[5] The caste hierarchy descends from Other Castes, followed by Backward Castes (BC), Most Backward Castes (MBC), Scheduled Castes and Scheduled Tribes (SC and ST respectively) at the very bottom.

5.1.2 Effects of the tsunami

Prior to examining the possible risk factors for morbidity and mortality, the tsunami's impact according to the survey results should be considered (Table 7).

Human impact. In terms of the tsunami's human impact; 231 individuals or 7.3% of the sampled population did not survive the disaster. Amongst the tsunami survivors, close to one out of five (19.6%) reported being rescued, with almost all rescuers (95.9%) being family members or other locals. Approximately 25.9% (n= 829) of the surveyed population were injured on the day of the tsunami. Of those that were injured, 11.0% sustained their injury while trying to rescue someone. Comparatively few individuals (n= 37) reported sustaining injuries in the month following the tsunami. Of those that were injured, 94.3% reported receiving treatment for their conditions, with private services (NGOs and private hospitals) providing a large proportion of the treatment events[6] (31.7%, n= 253 and 28.5%, n= 228, respectively).

The most common injuries sustained on the day of the tsunami were abrasions or lacerations (81.7%, n= 631), followed by sprains and strains (15.7%, n= 121), fractures or dislocations (11.0%, n= 85) and to a much lesser extent, electrocution or burns (1.3%, n= 10). The vast majority of injuries were sustained on the extremities (66.8% on the feet or legs, 41.3% on the hands, arms or shoulders) followed by the back (18.4%, n= 147), head or neck (15.1%, n= 120) and abdomen (11.3%, n= 90).

Questions on self-reported disability revealed that at the time of the survey approximately 2.3% of the injured population continued to suffer from a long-term disability and required partial to full-time care. A further 4.2% reported that despite being able to take care of all other needs, they could no longer work as a result of their tsunami injuries. Thus, at the time of the survey, a total of 6.5% of those injured as a result of the tsunami were no longer able to work and/or required ongoing care.

Livelihood impact. As a result of the tsunami, the proportion of households engaged in the fishing industry for their livelihood dropped by 7.8% (from 71.1% to 63.3%). In comparison, the proportion of households engaged in agricultural labour (12.9%) and small livelihood activities (9.4%) prior to the tsunami remained relatively unchanged by the event (post-tsunami proportions were 12.9% and 11.4% respectively). Notably, the tsunami had a significant impact on the rate of unemployment in severely affected hamlets, with household unemployment rising from 0.5% to 9.4% after the disaster, with the increase concentrated almost entirely in the fishing sector.

Housing damage. Of the 651 households interviewed, approximately 67.3% (n= 438) of houses were completely destroyed by the tsunami. Concrete houses were the most resilient with only 25% completely destroyed. At the time of the survey, 63% of households were still living in temporary shelters.

[6] Note that the same or multiple injuries may have required various treatments from various health providers. Respondents were therefore able to list more than one source of treatment.

Table 7. Summary of survey results of tsunami impact, Nagapattinam District

Human impact (incomplete data=64)	(n)	(%)
<u>Mortality</u>		
Number killed	231	7,4%
<u>Injury</u>		
Number of people injured	829	26,5%
Injured on the day of the tsunami	812	25,9%
Proportion of which were injured during rescue attempt		11,0%
Number neither killed or injured	2000	64,1%
Number of injured who sought treatment	782	94,3%
Total number of treatment events	799	
Sources of treatment :		
Government hospital	450	56,4%
Private hospital or clinic	228	28,5%
NGO	253	31,7%
<u>Self-reported disability as a result of tsunami injury</u>		
Able to work	686	93,3%
Unable to work, but independent	32	4,4%
Unable to work, long-term disability, requiring partial to full-time care	17	2,3%
Livelihood impact	(n)	(%)
Change in household occupation (fishing industry)	- 51	7,8% decrease
Change in unemployment after the tsunami	+ 58	8,9% increase
Housing damage	(n)	(%)
Number of dwellings damaged by the tsunami	574	88,8%
Undamaged	72	11,1%
Minor damage	52	8,0%
Moderate damage	84	13,0%
Completely destroyed	438	67,8%

5.1.3 Analyses of risk factors

This section presents the results of analyses aimed at identifying factors that may have increased the risk of mortality and injury to persons exposed to the tsunami. Potential individual vulnerabilities were examined followed by analyses of factors related to household characteristics and context. Table 8 displays the relative risks and related statistics for the factors presented below.

Gender is commonly considered a factor that affects the risk profile of an individual in disasters. It should be noted that when comparing those affected (in this case, those injured or killed) by the tsunami, males and females are equally represented. However, the proportions of dead or injured between the two sex groups were significantly different.

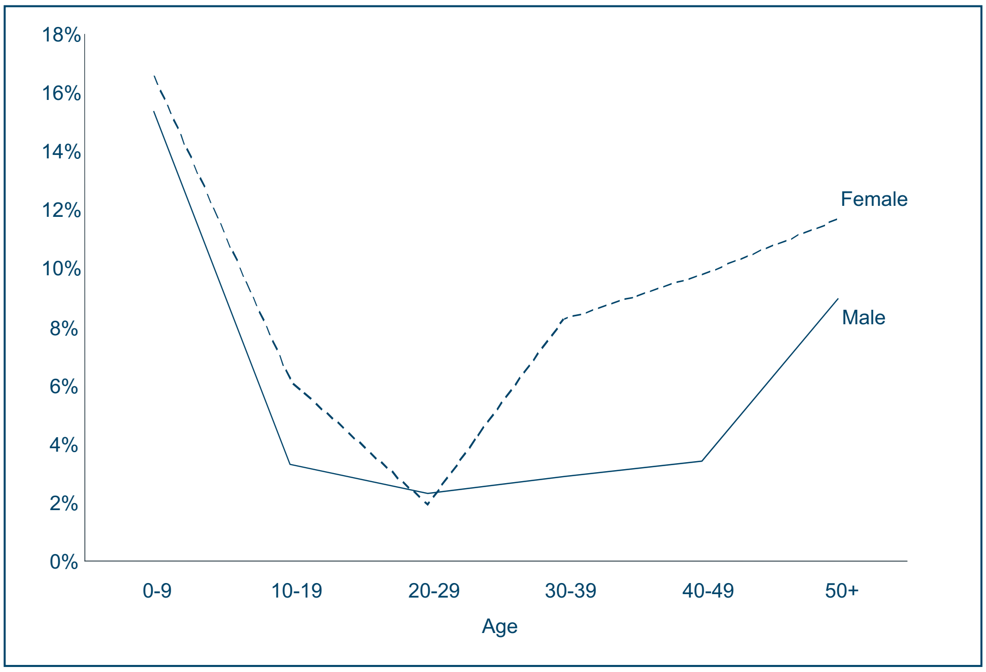

Figure 5. Mortality by age and gender

As Figure 5 illustrates, the majority of the deaths were females (60%) and 8.6% of the females exposed to the tsunami died compared to 6.0% of all men ($\chi^2 = 7.7$, $\rho < 0.01$). Relative risk ratio indicated a 40% higher risk of deaths for women from the tsunami. On the other hand, a higher proportion of males suffered from injuries.

Age[7] is also a common factor defining vulnerability to death and disability in many disaster contexts.

As depicted in Figure 6, children suffered significantly more casualties compared to injury cases, while the opposite was the case for the adult population. Children essentially either died (from their injuries or drowning) or escaped the tsunami unharmed. The death/injury ratio for this age group was 3:1; indicating that for every injured child, there were three that died.

In contrast, many more adults sustained injuries relative to the numbers who actually died. The death/injury ratio in this case being 0.2 deaths per injury or for every adult death, there were 5 injured.

[7] Age was recorded in five year age groups except those less than one year who formed a category of their own. For the purposes of analyses, these were recoded in three categories; children (<15 years), adults of working age (15-50 years) and elderly (50 years and over).

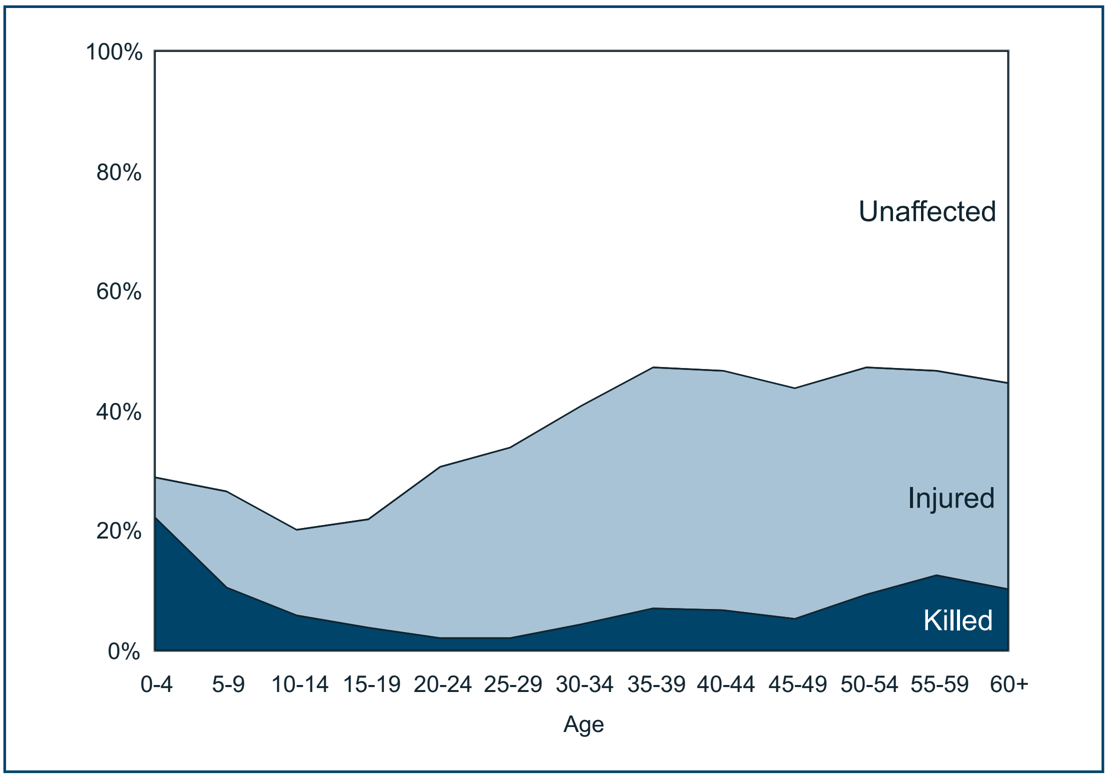

Figure 6. Post-tsunami outcome by age

Mortality was significantly heterogeneous between children (<15 years), adults of working age (15-50 years) and elderly (50 years and above) ($\rho<0.001$) (refer to Table 8 for the results of tests of significance for differences among the proportions in each age category). Deaths among children and the elderly were more than twice the proportion recorded for the adults of working age.

Notably, analyses of the age-gender interaction revealed that the heightened mortality risk linked to being female only applied to women between 15 and 50 years of age. In this age category, women demonstrated a significantly higher mortality than their male counterparts.

Warning data was available for 3088 individuals, 13% of whom reported having received some form of warning, the vast majority (89%) of which were informal warnings from family or friends. Those who did not receive a warning were three times more likely to have died (RR 2.9, $\rho< 0.001$) compared to those who had not been warned (Table 8).

Physical isolation was also a significant risk factor for death and injuries. More than 13% of those who were reported by the family to have been alone at the time of the tsunami died compared to half that proportion among those who were with another person.

Information on the level of **education** was reported for 2862 individuals more than five years of age. Of these, 28.9% (of which females = 69.1%, males = 30.1%) reported having no formal education. Compared to the "no education" cohort, individuals with at least one year of schooling demonstrated a lower risk for both mortality and injuries, even when controlling for potentially confounding variables such as age, gender and location (Table 8). It should be noted that there was no significant difference between years of education and swimming ability.

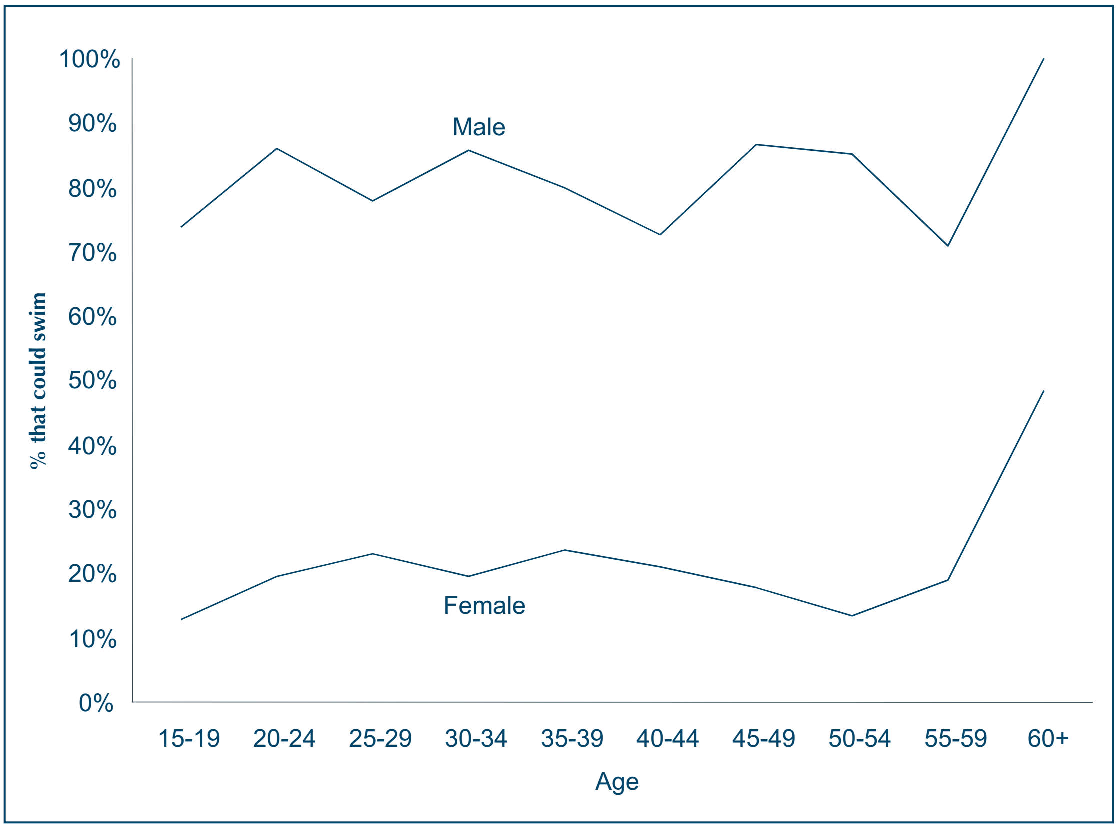

Figure 7. Swimming ability by age and gender

Finally, we explored individuals' **ability to swim** as a potentially protective factor for death from the tsunami waters. All persons less than 15 years of age were excluded from this analysis, which was based on swimming information on 2109 individuals including those who died. Of these, nearly half were swimmers and among whom 2.8% died. In contrast, the mortality among non-swimmers was 6.4%, a highly significant statistical difference.

The swimmers, who were more able to save themselves from drowning, presented, as a consequence, a higher proportion of injuries compared to the non-swimmers.

While the protective benefit of swimming ability was reflected in males and females equally, as illustrated in Figure 7, there was a significant difference between the proportion of males and females who were able to swim. While 64.2% of men could swim, amongst women the figure was significantly lower with only 15.9% able to swim ($\rho<0.001$).

Risks at the **household level** were significant for three characteristics. First, families whose main household occupation was fishing or related activities presented a significantly higher proportion of deaths with a relative risk of 2.4 ($\rho<0.001$) compared to those who were not engaged in this industry.

Second, proportionately twice as many people died among those living close to the sea (<200m), compared to others. This was true regardless of the type and quality of housing. In addition, people living close to the sea were also more likely to sustain injuries. The significance of this variable is underscored by the fact that regardless of an individual's location at the time of the tsunami, the distance of their dwelling from the sea appeared to have an impact on their mortality risk. Regardless of whether people were on the beach, at sea, at the jetty, at home or elsewhere in the village when the tsunami hit, the risk of death remained inversely correlated with the distance of their dwelling from the sea (see Figure 8).

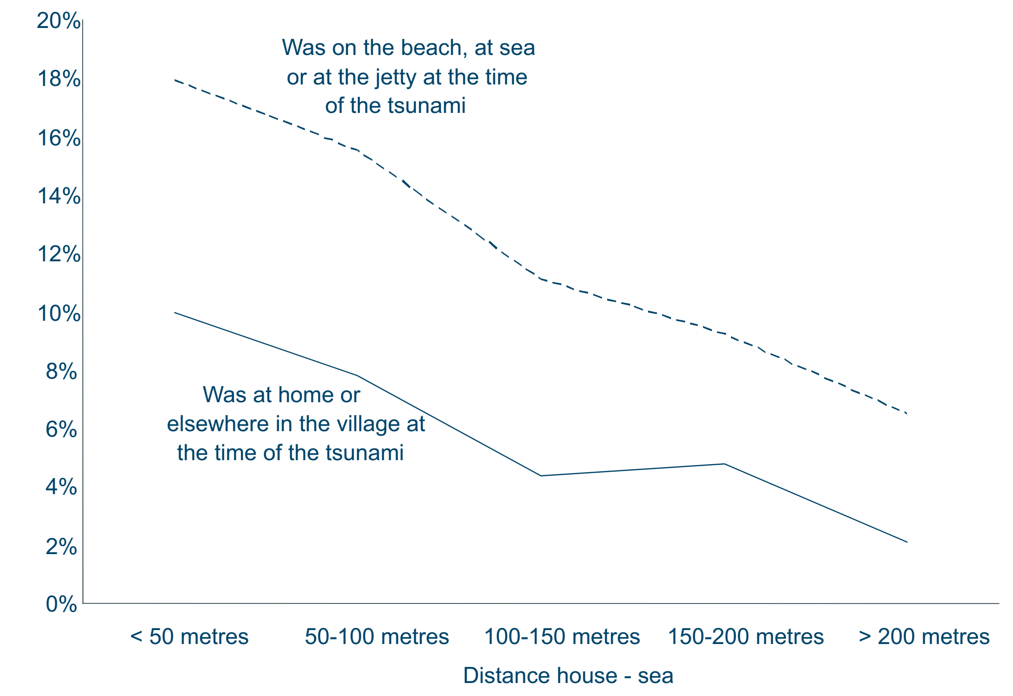

Figure 8. Proportion of deaths by location of dwelling and individual at time of tsunami

Third, the results suggest that dwellings with concrete roofs may have offered protection to the tsunami exposed population from death and injury. Only 4.6% of those living in concrete roofed houses died compared to nearly 8% among the others. This effect was retained even when controlling for distance to the sea, suggesting that stronger buildings made a significant difference to the risk of dying or being injured as a result of the disaster.

Table 8. Summary of results of risk factor analyses

Gender	(n)	(%)	Unaffected	Injured	Killed
Males	1547	49,4%	66,4%	27,7%	6,0%
Females	1583	50,6%	67,2%	24,3%	8,6%
			OR (female)=	0,8	1,5
			RR (female)=	0,9	1,4
			p (female)=	***0,03***	***<0,01***
Gender of the head of household	(n)	(%)	Unaffected	Injured	Killed
Male	2407	76,9%	66,8%	25,6%	7,6%
Female	723	23,1%	66,2%	27,3%	6,5%
			OR (Male)=	0,9	1,2
			RR (Male)=	0,9	1,2
			p (Male)=	*0,36*	*0,337*
Age	(n)	(%)	Unaffected	Injured	Killed
Under 15	963	30,8%	75,2%	12,9%	11,9%
15-50	1807	57,8%	65,0%	30,9%	4,1%
Above 50	356	11,4%	53,6%	36,0%	10,4%
			OR (<15)=	0,3	2,5
			RR (<15)=	0,4	2,3
			p (<15)=	***<0,001***	***<0,001***
			OR (>50)=	1,7	1,6
			RR (>50)=	1,4	1,5
			p (>50)=	***<0,001***	***0,02***
Caste	(n)	(%)	Unaffected	Injured	Killed
Backward caste	382	12,3%	71,7%	24,1%	4,2%
Most backward caste	2426	78,0%	66,3%	26,4%	7,3%
Scheduled tribe/caste	182	5,9%	68,1%	25,3%	6,6%
Other	120	3,9%	57,3%	22,7%	20,0%
			p (X^2)=	*0,65*	***<0,001***
Occupation	(n)	(%)	Unaffected	Injured	Killed
Fishing industry	2313	73,9%	64,6%	26,8%	8,6%
Agricultural labour	256	8,2%	72,6%	23,6%	3,8%
Other occupation	552	17,6%			
No employment	10	0,3%			
			OR (fishing)=	1,2	2,4
			RR (fishing)=	1,1	2,3
			p (fishing)=	*0,07*	***<0,001***
Location at the time of the tsunami	(n)	(%)	Unaffected	Injured	Killed
At sea	147	4,7%	48,9%	39,1%	12,0%
On the beach	492	15,8%			
At the jetty	37	1,2%			
At home	2135	68,6%	71,5%	22,5%	6,0%
Elsewhere in village	180	5,8%			
Other	121	3,9%			
			OR(sea,beach, jetty)=	2,2	2,1
			RR (sea, beach, jetty)=	1,7	2,0
			p (sea, beach, jetty)=	***<0,001***	***<0,001***
Distance house to the sea	(n)	(%)	Unaffected	Injured	Killed
< 200 metres	2106	67,3%	62,3%	28,3%	9,4%
> 200 metres	1021	32,7%	75,9%	21,2%	2,9%
			OR (<200 metres)=	1,5	3,4
			RR (<200 metres)=	1,3	3,2
			p (< 200 metres)=	***<0,001***	***<0,001***

Alone at the time of the tsunami	(n)	(%)	Unaffected	Injured	Killed
Alone	426	13,9%	47,8%	38,8%	13,4%
Not alone	2640	86,1%	69,4%	24,3%	6,3%
			OR (Alone)=	*2,0*	*2,3*
			RR (Alone)=	*1,6*	*2,1*
			p (Alone)=	***<0,001***	***<0,001***
Warning	(n)	(%)	Unaffected	Injured	Killed
Not warned	2687	87,0%	66,2%	25,9%	7,9%
Warned	401	13,0%	70,1%	27,2%	2,7%
			OR (Not warned)=	*1,1*	*3*
			RR (Not warned)=	*1,0*	*2,9*
			p (Not warned)=	***0,60***	***<0,001***
Roof type	(n)	(%)	Unaffected	Injured	Killed
Concrete	325	10,4%	75,7%	19,7%	4,6%
Tiled	342	10,9%	65,7%	26,7%	7,6%
Thatched	2401	76,7%			
Tarpaulin	24	0,8%			
Tin	39	1,2%			
			OR (Concrete)=	*0,7*	*0,6*
			RR (Concrete)=	*0,7*	*0,6*
			p (Concrete)=	***<0,01***	***0,05***
Ability to swim	(n)	(%)	Unaffected	Injured	Killed
Could swim	1000	47,4%	60,0%	37,2%	2,8%
Could not swim	1109	52,6%	65,7%	27,9%	6,4%
! Only people older than 15			*OR (Could swim)=*	*1,5*	*0,4*
			RR (Could swim)=	*1,3*	*0,4*
			p (Could swim)=	***<0,001***	***<0,001***
Education	(n)	(%)	Unaffected	Injured	Killed
No education	828	28,9%	57,6%	33,1%	9,3%
At least 1 year of education	2034	71,1%	70,0%	25,5%	4,5%
! Only people older than 5			*OR (No education)=*	*1,4*	*2,2*
			RR (No education)=	*1,3*	*2,1*
			p (No education)=	***<0,001***	***<0,001***

5.2 Focus groups

The focus group findings confirmed certain survey findings and provided additional information to consider for future preparedness strategies.

Firstly, both the findings from the focus group discussions and survey responses confirmed the lack of an effective warning system in Nagapattinam District. Most people who were "warned" received their warning informally. Only a very small number mentioned a formal warning of some sort from village authorities, and very few received a broadcast warning.

In general, the feedback obtained from focus group participants confirmed that there was almost a complete lack of awareness or knowledge of tsunamis. The lack of awareness meant that local people did not understand the signs of a tsunami (including the receding sea water) and therefore could not react appropriately to save themselves.

According to the **women's focus groups**, women may have been more at risk because they stayed behind to save or search for their children while others escaped. Furthermore, women who had lost their clothes in the tsunami may have been hesitant to leave the water or may not have escaped as quickly as possible due to the cultural shame associated with exposing their bodies. This face-saving behaviour however, may have increased their risk of injury or death.

The **doctors' focus group** revealed that many people sustained injuries or likely drowned because they became caught in fishing nets which had not been properly stored and were therefore washed in with the tsunami. Many impact injuries were also caused by boats which, in the absence of a secure marina, were washed into populated areas. Other environmental hazards for people during the tsunami were the thickets of thorny shrubs which grow in profusion along the Nagapattinam coast. According to the focus groups, these were a common cause of injury as many people were reportedly washed into them when the tsunami hit.

The focus groups also drew attention to weaknesses in the emergency health management of the health response. Immediately following the tsunami, most of the collection of bodies was done by local people with no medical training. There was neither official confirmation of death nor, in some cases, proper identification of the bodies. Instead, like in other tsunami-affected regions, bodies were hastily buried on a scientifically-unfounded fear that they posed a health risk to the surviving population.

Furthermore, the District Hospital was partially flooded by the tsunami and therefore could not respond adequately to aftermath of the disaster. At the same time, many Primary Health Centres (PHCs) were understaffed and under-resourced at the time of the disaster[8].

According to the **NGO focus group** participants, one of the major problems following the tsunami was the lack of access to medical services due to roads being completely blocked and the delays in clearing the debris which in turn hampered rescue and relief efforts.

Furthermore, a lack of adequate signage added to the confusion following the tsunami as people did not know where to go to seek treatment for the injured.

[8] According to the doctors participating in the focus group, the lack of adequately trained medical staff to deal with the health consequences of the tsunami probably also reflected a long-running problem that the health department has had with attracting specialists to work in the more provincial areas of the district.

5.2.1 Post-Tsunami relief efforts

The NGO focus group highlighted the concern that there were certain population cohorts, namely the Dalits or Scheduled Tribes (formerly referred to as the "untouchables" or lowest caste members) in the tsunami-affected population who were subject to discrimination from higher castes in the community and therefore had great difficulty accessing the relief material. Other low castes, the Scheduled Castes, which tend to comprise mainly the landless and agricultural workers, were also neglected. According to the NGO representatives, ensuring the balanced distribution of aid was particularly problematic in communities that contained a mix of fishing families, Dalits and agricultural families. In fact, some NGO representatives described meeting resistance from fishing families when they attempted to establish community kitchens for both the Dalits and the fishing communities.

The fishing families, as opposed to those from other sectors, represented quite a powerful, well-organised group, who established their own relief committee in addition to the regular system. While many fishing families lost their means of income and were the focus of much of the relief and livelihood reconstruction efforts, other sectors of the population such as street vendors and artisans were almost entirely overlooked. Finally, concerns were raised that when NGOs from outside the region arrived and did not understand the local situation, the fishing community were able to take greater advantage of the situation.

Another issue raised by the NGO focus group was that women's needs (for example, their need for privacy, sanitary napkins, milk for their infants) tended to be overlooked during the relief effort. Concerns were also expressed that alcohol consumption and alcoholism amongst men and adolescents had increased since the tsunami.

In describing how the tsunami has affected them, both the men and women from the fishing families described the mental anguish they were continuing to endure. Common complaints included feeling fear, loss of hope, loss of happiness, depression, feeling weak, body pains and digestion problems, nightmares, confusion, loss of social contact and concern about the future.

The women's focus group mentioned that they had received little in the way of monetary compensation. In many cases, their husbands received the cash however there were problems of the men spending the money on alcohol and of increased domestic violence towards women. The women also mentioned that one of the temporary shelter sites caught fire and everything was destroyed.

6. Discussion

This study was undertaken with both scientific and policy objectives in mind. These included to statistically measure the relative risks of death and injury among those who were exposed to the effects of the tsunami and to examine these risks in the light of underlying factors that lend themselves best to policy and programme intervention.

Prior to discussing these findings in detail however, a number of limitations have to be acknowledged. Firstly, it should be stressed that information on the deceased and other members of the household were obtained by questioning a single member of the household. This has its inherent limitations as it relies on the knowledge of the respondent, who may not have been witness to, for example, the exact location and situation of the deceased at the time of the tsunami. Furthermore, as with any retrospective study of this kind, the effects of recall bias must be acknowledged.

Furthermore it should be noted that there was limited statistical power with regard to certain factors because of insufficient cell size. For example, other disaster literature (5) had identified physical disability as a risk factor yet in this case the number of people with pre-existing physical or mental disabilities was too small in the current sample to generate significant statistical analyses. Further case-control studies would have to be conducted to examine this specific risk factor in greater detail.

Despite these limitations, the current study has revealed a number of key risk factors for death and injury as a result of the tsunami, from which key policy implications may be identified.

6.1 Key risk factors and the implications for risk reduction and preparedness

6.1.1 Gender and swimming ability

Like most adverse events, mortality risk associated with age is a U-shaped curve; with higher mortality amongst the young (in this case, under 15 years old) and senior (above 50 years old) cohorts. It was particularly notable that the high death rate amongst children was accompanied by very few injury cases, suggesting that amongst youngsters, evacuation or shelter to avoid exposure to disaster conditions is particularly critical. In addition, this study corresponds with what has been reported in other tsunami-affected regions – that the death toll for women was significantly higher than that for men.

However the current results reveal that the importance of gender as a risk factor varies significantly depending on age and ability to swim. For example, the results suggest that in fact it was only women between the ages of 15 to 50 years that had a heightened mortality risk: for children under 15 and for seniors over 50 years of age, the difference between the genders disappears.

This heightened risk for women has been attributed to a combination of factors including biological, physical, social and cultural differences. For example, women in this age bracket are of child bearing age and many may have had dependent children in their care. In an emergency situation such as the tsunami, this may have hindered their ability to escape. However the current results suggest that a major confounding factor for the increased death rate amongst women was their inability to swim (Figure 9).

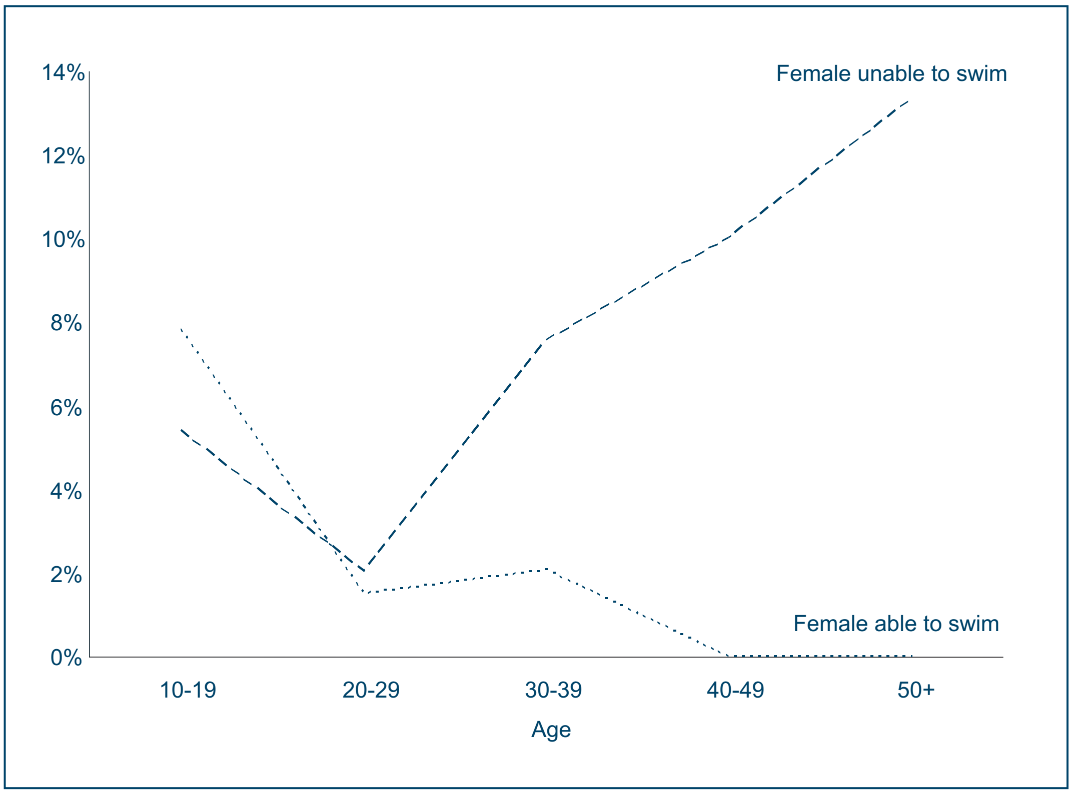

Figure 9. Proportion of deaths amongst women as a function of age and ability to swim

Contrary to the suggestion by Jonkman and Kelman (12), swimming ability (even in turbulent conditions) did reduce the overall mortality rate by more than 60%. It should be noted however that in this case, the ability to swim was highly correlated with gender, as male swimmers were more than four times more common than females. The protective function of swimming ability was demonstrated by the lower death rate amongst women who could swim compared to those who could not and the fact that this group were not at greater risk than their male counterparts of the same age.

However, while the death rates for men may have been lower than that for women, the pattern of injuries clearly indicated that men remained at high risk in this regard. Notably, a considerable proportion of the injuries sustained by adult men on the day of the tsunami were related to their involvement in rescue attempts. It is possible that their ability to swim may have encouraged men into rescuing action and that this, combined with a greater physical strength to cling to stable objects and resist water forces, resulted in more men than women avoiding death, but led to their increased risk of injury.

Findings such as these suggest that developing policies and programs to actively promote and enhance the swimming skills of coastal populations, with a particular focus on women and girls, could help to mediate the gender risk during such catastrophes. Furthermore, empowering individuals with a greater capacity to save themselves may reduce the need for risky rescue attempts.

Although the inability of women to swim appeared to account for the heightened mortality risk amongst women, other areas of gender inequality such as differences amongst the literacy rates between males and females deserve consideration for the implications it has for all sectors of development, including the success of disaster preparedness and prevention programmes. For instance, the information or material used in early warning or community awareness training need to be designed for the illiterate population, most of whom are women.

6.1.2 Location at the time of the tsunami and distance of dwelling from sea

It has been widely observed within the literature that the fishing industry was hard-hit by the tsunami. Although being a member of a fishing industry household was an important risk factor for mortality, the impact of this variable can be attributed to the whereabouts of the individual at the time of the tsunami and the location of their dwelling. For instance, regardless of household occupation, individuals from households less than 200 metres from the sea were at significantly greater risk of death or injury. However of all households located less than 200m from the sea, 87% were involved in the fishing-industry with other household occupations representing the majority of dwellings more than 200m from the sea. In addition, at the time of the disaster, members of fishing households were also more likely than other villagers (= 0.001) to be in high risk zones (at sea or on the beach) where they would have been exposed to the full force of the tsunami.

In line with common wisdom, the current results confirm that living close to the sea increases mortality risk from sudden sea-related disasters. In fact, for tsunami-affected populations in Nagapattinam District the mortality risk was 2.5 times higher for populations living close to the sea, reinforcing the argument for regulating human settlements in coastal zones. In the case of Tamil Nadu however, the strict implementation of zoning regulations would imply a major relocation program, which in turn would have considerable livelihood implications particularly for poor fishing communities which rely heavily on their proximity to the sea (11). Relocating may be unfeasible for fishing families for whom public or private transport to the fishing boats may be unaffordable or even non-existent at the hours required.

In addition to location, the current study investigated whether lone individuals were more at risk during the tsunami. Although few studies have examined the characteristics that determine survival in mass catastrophes, some authors have noted that isolated individuals (those living alone or in the absence of company) have a higher risk of dying in acute disasters (5). The results of the current study appeared to support previous findings as people who were by themselves or far from crowds at the time of the tsunami recorded more than twice the risk of dying than people who were in group[9].

6.1.3 Construction material

Concrete structures (in our study, roofing material) appeared to provide protection from death and injury. It is likely that sturdy roofs enabled people to escape the tsunami waters[10]. Indeed, as reported by the focus group participants, many people were saved in one hamlet because they were able to escape the water by clambering onto a bridge which was being constructed in the area. It is likely that had more houses and other structures been able to withstand the tsunami waters there would have been fewer casualties.

Reconstruction efforts should also be focussed on adequate storage sheds for fishing equipment and marinas for boats. According to focus group feedback, constructing and mandating the use of disaster-resilient storage sheds could have reduced the number of deaths and injuries caused by debris.

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[9] The interpretation of the variable "alone" has to be taken with some caution. Validation of the data suggested that "being alone" was also regarded as "being away from crowds". In this way for example, two people who may have been together on the beach but away from crowds of people, were often reported as being alone.

[10] It should be noted however that roofing quality may also be an indicator of higher socio-economic status which is likely to introduce other confounding factors and contribute to lower mortality risk during disasters.

6.1.4 An absence of warning

Except for members from just two households who reported receiving a media broadcast, official warning systems were absent in the hamlets surveyed. Of the 13% who reported receiving a "warning", almost all identified it as a verbal warning from family or friends. According to our results however, even this informal warning may have mediated the risk of mortality by 65%. When controlling for the individuals' location at the time of the tsunami, the protective effect of receive a warning remained significant, suggesting that the effect was not just due to the confounding factor of being at a safer distance from the sea.

The current results are consistent with other studies which have shown that timely warning systems can play a significant role in reducing the human impact of such disasters (38). It is therefore imperative that the proportion who receives a disaster warning increases. The fact that more than half of the surveyed population owned either a television or radio at the time of the tsunami suggests that media broadcasts could be a reasonable channel for early warning information in the future. Other systems of local communication would be required (a siren for example) to ensure the warning is conveyed to as many people as possible.

Finally, while the development of early warning systems is an issue of high priority amongst the international community response to the tsunami, past experiences have demonstrated that a detection and warning dissemination system alone is insufficient. For example, early-warnings were disseminated prior to the Orissa cyclone in 1999, yet the disaster still killed thousands. Studies suggested that it was not "the lack of a professional and well-established warning system that is the key point, but rather the awareness of the recipients to the actual risk and the necessary steps to minimise or avoid it" (39) (p. 378). In the case of the 1991 Bangladesh cyclone it has been reported that despite the dissemination of cyclone warnings, a considerable proportion of the population failed to act due to the belief that they were false alarms (29).

Shelter and/or evacuation options must be available and populations must know how to access them. As the lessons from Hurricane Katrina in 2005 emphasised, the responsibility of the public authority goes beyond simply issuing the warning. In the case of Tamil Nadu, not only was there no effective warning system, but the few cyclone shelters, constructed during the early 1990s at some cost, have reportedly fallen into disrepair and are currently serving little or no purpose. A practical solution would be to provide stronger and permanent work structures or places which can also provide protection during cyclones, coastal floods, storm surges and tsunamis.

While the construction of improved, disaster-resilient housing should remain a long-term goal in coastal areas, multi-purpose shelters[11] may serve as a good option in the interim. Chowdhury et al. (29) have suggested that rather than investing in a few large shelters, it is better to construct numerous smaller shelters so that they are more easily accessible and may be more easily utilised (for such purposes as schools, health or cultural centres) in normal conditions.

Without wanting to undermine the value of an early warning system, it should also be noted that evidence from areas without official early warning systems suggests that the experience of residents can be sufficient to instigate the evacuation of coastal areas after seismic activity (35). In the case of the Indian Ocean tsunami the lack of awareness and preparedness for the disaster was demonstrated

[11] Multipurpose shelters have to be carefully designed taking into consideration such factors as accessibility during flood conditions. They would need to be able to withstand cyclonic winds, be elevated to avoid flood waters, with stairs to the roof, be serviced by latrines and water supplies and be regularly inspected and maintained.

by the lack of action, even after the tell-tale sign of receding sea water. Such considerations underline the importance of community awareness-raising regarding disaster preparedness and emergency programs.

6.1.5 Public health considerations

While disease and other public health considerations were not the focus of the current study, the survey did reveal that 25.9% of the population were injured on the day of the tsunami. Of those that were injured, the vast majority received some form of medical treatment. While many injuries were treated in government hospitals, the largest proportion (60.2%) received medical attention from private (that is, private for profit and private non-profit) institutions such as private hospitals and NGOs. This suggests that there was a heavy reliance on the non-public health sector following the tsunami in Tamil Nadu. Such patterns of post-disaster health care emphasise the importance of including private health providers in emergency response planning and disaster training. Further research is required to determine to what extent this pattern of health care is reflected following other acute disasters in other regions.

Finally, it should be noted that planning for emergency responses in hospitals and health centres may be better informed by epidemiological evidence. For example, the weighted average death/injury ratio reported by Alexander (14) (see Table 2 displayed previously) was 0.28, a figure which corresponds with the death/injury ratio observed in the current study (0.28)[12]. Notably, if observed to be stable within a certain range, such ratios may facilitate the rapid assessment of medical needs by estimating the number of injured in relation to the number of deaths. Unfortunately, while death to injury ratios may help in planning emergency preparedness for hospitals and health centres, such epidemiological evidence is lacking.

6.1.6 Long-term considerations

The tsunami relief and recovery effort has been extremely well-funded. Typically, when there are excess funds after disasters, money is absorbed through investment in large scale infrastructure projects. However in many of the tsunami-affected regions, disaster relief has become an issue in poor communities unable to absorb the sheer quantity of funds available.

In deciding how these funds may be invested to ensure positive, long-term changes for the affected populations, the current findings draw attention to two vulnerable sub-groups: those that are now permanently disabled and children who have lost their mothers as a result of the tsunami.

Firstly, according to the current study, the tsunami-affected population reporting a permanent disability leading to an inability to work was approximately 2.3%. The fact that this group represents such a small proportion of the population suggests that government re-training programs and/or pension schemes may be feasible options.

Secondly, the high concentration of mortality amongst women of child-bearing age implies an increase of motherless children in tsunami-affected regions. As previous studies have shown, children who have lost their mothers are a highly vulnerable group, exhibiting higher mortality rates than their peers (40, 41). Funding should therefore be directed at programs aimed at supporting such children by ensuring their continued access to basic needs and education, while at the same time rebuilding the livelihoods of their communities.

[12] At present, comparable death and injury information from across the other 2004 tsunami sites is not available.

A final consideration pertains to the benefits of education. While further research is required to unpack the influence of education on individual risk factors during extreme events, the current data suggests that people who had received at least one year of education were at lower risk of both death and injury due to the tsunami than those with no history of education. Even after controlling for potentially confounding variables, this significant difference remained. Some formal education may therefore equip people with certain skills or knowledge which can have protective benefits during acute disasters and should be a consideration for long-term development policies.

7. Conclusions

The findings of this study are significant in that they provide new insights into mortality and injury risk factors as a result of the 2004 Indian Ocean tsunami and confirm and quantify claims which had so far remained unmeasured.

According to the study results, several vulnerable groups were identified. These include young children, the elderly of both sexes and women between 15 and 50 years of age, all of whom demonstrated the highest risk of death during the tsunami. Swimming ability was a significant protective factor against mortality and it is likely that more women would have survived the tsunami if they had known how to swim.

As expected, individuals from fishing families and from households located less than 200m to the sea had a much higher mortality risk than others. While the two factors were closely linked, the most influential risk factor was the proximity of an individual's dwelling to the sea.

Although these coastal communities did not receive a formal warning of the tsunami, the results suggest that even word-of-mouth warnings from neighbours or friends may mitigate the mortality risk during acute disasters.

Another risk factor highlighted by the findings was linked to people who were alone or away from crowds at the time of the tsunami. It is possible that living with other people may serve as a protective factor by facilitating word-of-mouth warnings and via the presence of potential rescuers.

Finally, an area worthy of greater attention is the death to injury ratio of seismic tsunamis. The results of this study correspond with previous tsunami data as reported by Alexander (14) which reveal an average weighted death to injury ratio of 0.28. These ratios provide a rough estimate of expected burden of injury or deaths facilitating more efficient hospital and emergency care planning.

8. Recommendations

Drawing on the findings of this research, a number of key policy recommendations for reducing the risk of mortality and injury as a result of acute disasters such as the 2004 Indian Ocean tsunami have been identified:

1. Community disaster preparedness programs and policies should focus on specific vulnerable target groups.

The mortality profile in Nagapattinam District and elsewhere across the tsunami-affected region demonstrates the heightened vulnerability of women in such communities and is a major issue that should be specifically targeted in any future disaster preparedness and early warning programs. Particular factors to be taken into consideration include women's social role as carers, their higher illiteracy rates and lack of swimming ability. In addition, small children, elderly and those in isolated occupations or living alone should be targeted to ensure that they are not excluded from community warning systems. Preventing deaths among women in child-bearing ages deserves particular attention on the basis that epidemiological evidence demonstrates that motherless children are more prone to health problems and lower survival rates.

2. Early warning systems for poor communities should be carefully designed taking into account the reality of the prevailing levels of literacy, poverty and technological capacity.

In the absence of an appropriate alert system, most of the tsunami-affected population in Nagapattinam District had very little, if any, warning of the impending tsunami. Consultations with the local population suggest that an early warning could have saved many lives. However considering that tsunami events in this part of the world are extremely rare, warning systems need to be multi-hazard and based on a thorough assessment and development of information dissemination procedures. For instance, the surveyed population (and particularly women) tended to have low literacy levels; a factor which has implications for warning design and dissemination methods. Furthermore, whilst functioning televisions and/or radios were available in most households (suggesting that broadcast warnings could be a viable option) this was not the case for landline or mobile phones. Finally, low-tech, grass-roots solutions such as loudspeakers should not be neglected in the process of developing sophisticated regional or national warning systems.

3. Disaster preparedness interventions such as mandatory swimming lessons for coastal populations should be mainstreamed into standard development programmes.

The ability to swim increases an individual's chances of survival during acute flooding events. States should therefore consider promoting and funding swimming lessons to coastal communities, tailoring such programs so that they target women and girls. The provision of specific courses on water rescues might also be considered, along with basic first-aid and disaster evacuation training.

4. Durable and pragmatic solutions for safer human settlements in coastal regions should be identified and implemented.

While proximity to the coast is a recognised risk factor, relocating poor populations that rely on access to the sea for their livelihoods may not be the most effective solution. Alternative approaches including the provision of subsidies for stronger, well-designed housing and materials could be implemented in conjunction with the application of appropriate building codes for public structures to improve the resilience of coastal communities' infrastructure to extreme events. Multipurpose shelters should be constructed and community disaster awareness and preparedness programs should be conducted, with evacuation procedures targeted at children and the elderly, who have a particularly high risk of dying in such acute disasters. Secure boat marinas and storage sheds for fishing equipment should be constructed and utilised.

5. Preparedness and recovery policies must include specific provisions for motherless or orphaned children, as well as people with long-term disabilities as a result of major disasters.

Permanently disabled individuals and motherless children have unique needs which require assessment and would benefit from appropriate assistance from governments and NGOs throughout the tsunami relief programs and beyond.

6. Effectiveness of disaster preparedness can be greatly enhanced by further research on risk indicators and ratios.

Finally, further research is required in order to produce quantitative data on death to injury ratios and the competing value of different mortality and injury risk factors in acute disasters. Such findings should be considered in the future planning and improvement of emergency response procedures and medical staff training.

Clearly, the tsunami disaster generated extraordinary financial generosity and a political willingness to move forward on effective disaster preparedness and prevention interventions. The international community should therefore capitalise on this opportunity to implement sustainable and appropriate mechanisms to reduce the human impact of future disasters in developing and developed countries alike. It is however, only through ongoing systematic research that a stronger evidence base of individual risk factors for death and injury – and therefore a better foundation for informed policy decisions – will be achieved.

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