The Sumatra-Andaman Earthquake and Tsunami of 2004: The Hazards, Events, and Damage

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Abbreviations:
UN = United Nations
UNEP = United Nations Environmental Programme
UNICEF = United Nations Children's Fund
UTC = coordinated universal time
WHO = World Health Organization

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Abstract
The Sumatra-Andaman Earthquake and subsequent Asian Tsunami of 26 December 2004 affected multiple countries in the Indian Ocean and beyond, creating disasters of a scale unprecedented in recorded history. Using the Conceptual Framework and terminology described in the *Disaster Health Management: Guidelines for Evaluation and Research in the Utstein Style*, the hazard, events, and damage associated with the Earthquake and Tsunami are described. Many gaps in the available information regarding this event are present. Standardized indicators and reporting criteria are necessary for research on future disasters and the development of best practice standards internationally.

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Introduction

This paper was developed by the Editorial Staff of *Prehospital and Disaster Medicine* (PDM) to provide a brief summary of the hazards, events, and damage related to the Sumatra-Andaman Earthquake and subsequent Asian Tsunami of December 2004. The summary serves as a frame of reference and context for the remainder of this issue of PDM. This issue is comprised of the summaries of the Conference on Health Aspects of the Asian Tsunami of 26 December 2004, convened by the World Health Organization (WHO) in Phuket, Thailand from 21–23 May 2005. The objectives of the Conference were to: (1) define what was done well; (2) define what could have been done better; (3) fill in the gaps in information and response, if any existed; and (4) create ideas to build the capacity to absorb the energy, buffer the damage, and enhance the responses to the damage when the next catastrophic event occurs. Every report included in the papers that follow attempted to meet these objectives and follow the structure suggested by the WHO.

It was beyond the scope of the Phuket Conference to provide background information about the event and the affected societies. Unfortunately, without this contextual information to provide an understanding of the events and the damage that resulted from the events, the proceedings from the Conference lose the potential to be more far-reaching. Once these observations and recommendations are read within the context of the event and damage, they can be applied to similar situations. Events and the resultant damage must be framed in a manner that facilitates comparison with other events.

This introductory paper seeks to provide the information about the Sumatra-Andaman Earthquake and subsequent Asian Tsunami of December 2004 using the Conceptual Framework and terminology described in the *Disaster Health Management: Guidelines for Evaluation and Research in the Utstein Style*.[1] This framework separates the hazards, events, damage, and functional deficits resulting from damage into different components (Figure 1). Also, it defines damage and loss of function with reference to the pre-event status of an affected society. The framework facilitates comparisons between events. Using this structure for the study of hazards, events, damage, functional deficits, and disasters should make it possible for assessing the impact

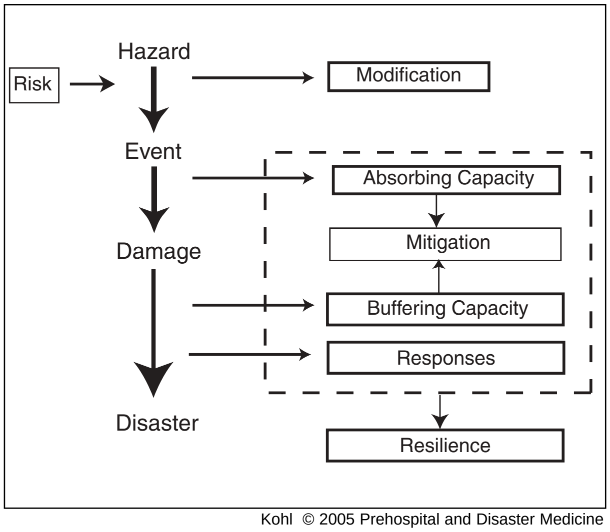

Figure 1—Flow from a hazard to a disaster

of all interventions. These interventions may be directed at the prevention of events, mitigating the damage created by events (enhancing the absorbing capacity), the ability to function with the effects of the damage created by an event (buffering capacity), and/or the responses to the damage created.

Background

The surface of the earth is not a continuous crust. Instead, fractures separate it into tectonic plates that grind and collide against one another as the hot interior of the earth shifts restlessly below. The rates at which the plates move range from 1–12 centimeters per year, and as a plate moves, its momentum often will conflict with that of a neighboring plate.[2] Rocks lock one plate against the other, restraining movement between them until the stress of restraining the plates exceeds the strength of the rocks. When this happens, rocks break, plates jolt into motion, and an earthquake results.

A tsunami is created whenever a large volume of seawater is displaced abruptly. Most tsunamis result from oceanic earthquakes, but other hazards such as volcanoes, landslides, and meteorites also can trigger a tsunami. To create a tsunami, an earthquake must have a large magnitude and abruptly deform the sea floor. Earthquakes that measure <6.5 on the Richter scale rarely produce tsunamis, and earthquakes measuring <7.6 rarely produce destructive tsunamis.[3] Even a large oceanic earthquake will not produce a tsunami if the earthquake does not abruptly deform the sea floor and displace a large quantity of seawater.

The potential energy stored in an undersea fault has the capability to produce both an earthquake and, by virtue of its undersea location, a tsunami. Not all fault ruptures produce tsunamis and several features distinguish earthquakes that trigger tsunamis from other earthquakes. In addition to magnitude, factors that determine whether or not an earthquake will produce a tsunami include: (1) the direction in which the fault slips; (2) the depth of water under which it occurs; and (3) the proximity of the earthquake focus to the seafloor.

First, an earthquake created by a vertical slip between two tectonic plates, known as a *thrust* earthquake, is far more likely to create a tsunami than is an earthquake created by two plates slipping past one another horizontally, known as a *strike-slip* earthquake (Figure 2). In a thrust earthquake, two overlapping plates are thrust toward one another (Figure 3). As the fault between the two plates ruptures, the densest plate slips beneath the other, a process known as *subduction*, and can result in a sudden rise or fall in part of the seafloor. If a sudden and large vertical movement in the seafloor results, it will displace the column of water above it. The water displaced by an abrupt change in the seafloor is not unlike the water displaced by a rock thrown into a pond. This displaced water creates waves that disperse the energy of the displacement by radiating outward like ripples on the pond's surface. Among thrust earthquakes, megathrust earthquakes are most likely to produce tsunamis, since they tend to produce the largest earthquakes in the world. As in other thrust earthquakes, megathrust earthquakes are created by vertical slippage, but a fault that creates a megathrust earthquake remains locked for longer periods of time, allowing it to build up more stress. The five largest earthquakes since 1900 all have been megathrust earthquakes.[4]

Second, due to the greater volume of water displaced, an earthquake that occurs below deep water is more likely to create a tsunami than is an earthquake that occurs below shallow water. When an earthquake abruptly displaces a large volume of water, it creates waves with tremendous wavelengths, an important feature distinguishing tsunamis from other waves. A wavelength equals the distance between one wave crest (high point in a wave) and the next. While wind-generated waves produce wavelengths of 5–20 meters, tsunamis can produce wavelengths >700 kilometers.[5]

Finally, the location of an earthquake focus, or point of stress release relative to the seafloor surface, also influences whether or not it will produce a tsunami. An earthquake focus can occur anywhere between the surface of the seafloor to 800 km below it in the Earth's upper mantel.[6] Due to its close proximity to the seafloor, an earthquake with a shallow focus is more likely to abruptly change the contour of the seafloor and, therefore, produce a damaging tsunami. An earthquake with a deep focus, on the other hand, might not cause a change in the surface of the seafloor. Not all earthquakes rupture the surface of the earth's crust.

When the primary event of an earthquake results in the secondary event of a tsunami, the tsunami may go undetected until it reaches shore. In deep ocean waters, tsunami waves barely are noticeable. In water >180 meters deep, for example, tsunami waves arrive in slowly rising peaks that rarely reach more than a meter in height. A tsunami wave rises slowly in deep water not because the tsunami is moving slowly, but because its wavelength is much greater than that of a wind-generated wave. Tsunami wavelengths are so great, as much as an hour may go by before an entire wave has passed the same point.[7] A wind-generated wave, on the other hand, will typically take 5–20 seconds to pass.[8]

As mentioned above, tsunami wave crests rise slowly in deep water due to the tsunami's enormous wavelength, and not because tsunamis travel slowly. On the contrary, in deep water, a tsunami wave can travel 500–1,000 kilometers per hour, but as a tsunami wave travels into shallow water, its speed, known as *celerity*, slows significantly due to friction with the ocean floor. The celerity of a tsunami can

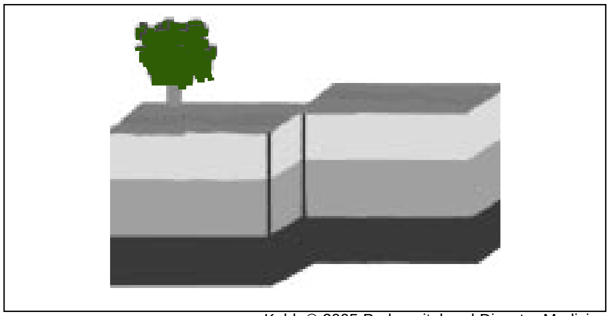

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Figure 2—A strike-slip fault (USGS)

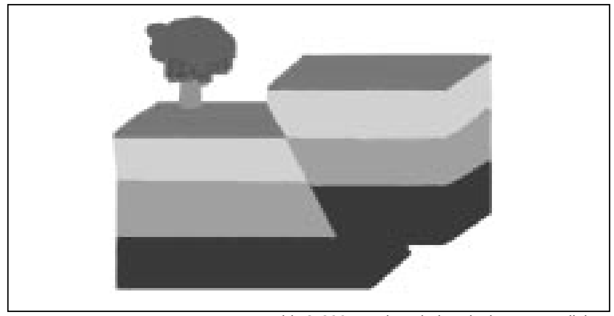

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Figure 3—A thrust fault (USGS)

be calculated at any given location by multiplying the square root of the depth of the water by the acceleration of gravity (9.8 meters per second squared).

Since a tsunami wave height remains short in deep water, a boat in the middle of the ocean can float safely as a tsunami passes below it. As a tsunami wave approaches shore, however, shallow water transforms it into taller wave. In shallow water, friction with the seafloor slows the tsunami wave; as the tsunami slows, its wavelength shortens, but much of what the tsunami loses in wavelength, it gains in height (Figure 4).

When a tsunami reaches shore, it may: (1) flood the shores without breaking, like a strong and rapidly rising tide; (2) arrive as a series of breaking waves; and/or (3) become a turbulent wall of water known as a *bore*. Most arrive without breaking, similar to the storm surge in a hurricane (tropical cyclone). Much of the damage attributed to tsunamis is caused by the current and floating debris as water rapidly rushes inland and/or back out to sea.

Much as the amplitude of an earthquake is measured by the Richter scale, a scaling mechanism also is available for tsunamis. This is a mathematical formula which computes a tsunami magnitude (M_t) based on measurements of the maximum crest-to-trough amplitude and distance from the epicenter to a measurement station along the shortest oceanic path.[9] This can be helpful for making rough estimates of damage.

Hazard

Seismic and tsunami activity is less common in the Indian Ocean than in the Pacific Ocean. However, the Sunda Trench, a subduction zone between plates in the Indian Ocean, has placed Indonesia among the most seismically active zones on earth.[10] Additionally, due to the Sunda Trench, also known as the Java Trench, the number of megathrust earthquakes that occur in the Indian Ocean is second only to the number of megathrust earthquakes that occur in the Pacific Ocean.

Although geologists do not expect the same fault segment to produce an ocean-wide tsunami of similar amplitude more than once every 400 years, other segments in the region still pose a significant hazard. Fault segments south of the Sumatra-Andaman Earthquake, for example, could create another devastating tsunami in the near future.[11] In addition, the stress released by the Sumatra-Andaman earthquake may have been distributed to segments that did not pose a significant hazard prior to the Sumatra-Andaman Earthquake.[3]

How a coastal community is oriented relative to a hazardous fault also is relevant to understanding which community is at risk of being exposed to a tsunami. According to geologists, coastal communities that face the side of a hazardous fault, assume a greater risk than those facing either end of the fault.[11] The Sumatra-Andaman Earthquake, for example, ruptured a fault that was primarily north-south in its orientation, sending the strongest tsunami waves to the east and west of the fault. Consequently, Bangladesh, a low-lying country north of the earthquake epicenter, lost fewer lives and suffered less damage than did perpendicularly oriented Somalia, a country significantly farther from the earthquake epicenter than Bangladesh. Unfortunately, reliable estimates as to where the most hazardous faults in the region lay since 26 December 2004 have not yet been mapped.[3]

Event

On 26 December 2004, centuries of built-up stress between the India and Burma plates broke the rocks locking them against each other in the Sunda Trench, and resulted in the Sumatra-Andaman megathrust Earthquake. Although the Sumatra-Andaman Earthquake was among the most complex geologists have seen, they can explain at least two reasons the fault between the India and Burma plates remained locked long enough to build-up the strain required to produce a megathrust earthquake. First, the shallow angle at which the India plate dips below the Burma plate creates a greater surface area of contact between the two plates allowing them to lock firmly against one another for long periods of time. Second, the India plate has cooled into a dense, solid crust, and therefore, resists melting. Consequently, the India plate locks against the Burma plate more than it would if it were less solid, since melting facilitates movement between plates.

The Sumatra-Andaman Earthquake, the largest in 40 years, ruptured an estimated 1,200 kilometers of fault line and created the deadliest earthquake in recorded history. The jolt in the slow collision between the India and Burma plates drove as much as 20 meters of seafloor under the Burma plate and released centuries of built-up strain. The resulting earthquake was massive, releasing enough energy to supply the United States for six months, or the equivalent of the energy contained in a 100-gigaton bomb.[12]

Although the Earthquake measured at least 9.0 on the Richter scale, enough to move the North Pole by approxi-

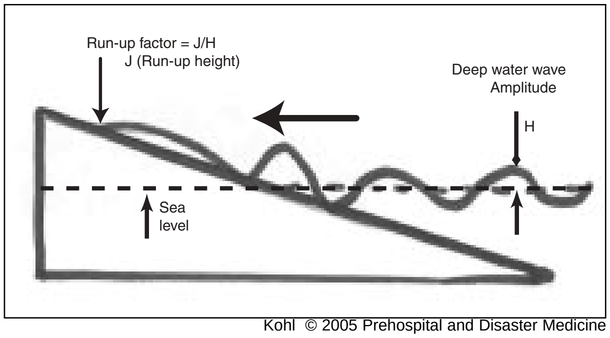

Figure 4—The decreasing wavelength and increasing wave height of a tsunami wave as it moves into shallow water and makes landfall (USGS)

mately 2.5 centimeters, earthquake magnitude was only one of several important factors that contributed to the creation of the enormous Tsunami that struck in December 2004.[13] At least three additional factors point to why the Sumatra-Andaman Earthquake produced the powerful Tsunami. First, the direction of fault slippage was more vertical than horizontal, allowing it to displace more seawater and create a larger tsunami than would a similar earthquake with more horizontal slippage.[3] Secondly, the earthquake occurred in deep water, up to 4,000 meters below the surface of the ocean, much deeper than the Richter scale 8.7 earthquake that occurred in the same region on 28 March 2005. Although the March earthquake was the second largest earthquake to occur in the last 40 years, its depth beneath the ocean surface measured 1,000 meters, and therefore, the resulting tsunami was hardly noticeable. Finally, the focus of the Sumatra-Andaman Earthquake was so shallow, the focus of energy release may have extended to the seafloor surface.[14] This shallow focus enabled it to lift the overlying portion of the seafloor up to five meters higher, displacing more than 30 cubic kilometers of seawater and generating tsunami waves that would grow to 30 meters in height along the west coast of Indonesia.[11,15]

Although earthquakes generally are classified as short-duration events, the duration of the Sumatra-Andaman Earthquake was long compared to most. The Sumatra-Andaman Earthquake ruptured for 10 minutes. During the Sumatra-Andaman Earthquake, the fault ruptured slowly for the first minute, then accelerated to 3 kilometers per second for the next four minutes before slowing down to 2.5 kilometers per second for the final six minutes.[11] However, the duration for which people exposed to an earthquake feel the ground shake differs depending on their distance from the earthquake epicenter and the geology of their location. For example, ground made of soft, wet sediments will shake like a bowl of jelly when an earthquake strikes, and shaking can last three times longer than it would if the ground were made of hard granite. However, even people located near the epicenter and on ground made of soft, wet sediments, probably did not feel shaking for the full 10 minutes the fault took to rupture. Nevertheless, they are likely to have felt strong shaking for at least several minutes. Typically, minor earthquakes shake for only a few seconds and strong shaking from major earthquakes does not usually exceed more than one minute.[6]

The fault slippage on 26 December 2004 created two events, an earthquake and a subsequent tsunami. From its epicenter, just off the western coast of Indonesia (3.307° N, 95.947° E), the Sumatra-Andaman Earthquake sent tsunami waves throughout the Indian Ocean and beyond.[16] The Sumatra-Andaman Earthquake and Asian Tsunami are separate, but related events. The Earthquake triggered the Tsunami, and therefore, was the primary event. The Tsunami, on the other hand, resulted from the Earthquake, and therefore, was the secondary event.[1] The onset of both events was sudden and their duration brief.

The averaged tsunami magnitude (M_t) of the Asian Tsunami was 9.1. This places the Tsunami among the five largest on record (Table 1).[9]

The Earthquake began its 10-minute rupture at 00:59 coordinated universal time (UTC) (07:59 local time), but triggered tsunami waves that would radiate outward for hours (Table 2). In deep water, the waves traveled quickly, as fast as a jet plane. Three and a half hours after the Earthquake, the Tsunami had reached every coast from the Maldives to Malaysia, and by the seventh hour, it had reached as far as the coast of Somalia. Proximity to the Earthquake epicenter, however, only was one factor that determined when a country would be struck by the Tsunami. The depth of the ocean water separating a country from the Earthquake epicenter also influenced arrival time.

A comparison of the Asian Tsunami's arrival time in Thailand with its arrival time Sri Lanka, for example, shows how its celerity changed with the depth of the water through which it traveled. The Sumatra-Andaman Earthquake epicenter lays 580 kilometers from Thailand and 1,815 kilometers from Sri Lanka.[17] Yet, the Tsunami took approximately 100–140 minutes to reach Thailand and only 100 minutes to reach Sri Lanka. Because the shallow Andaman Sea separated Thailand from the earthquake epicenter, waves traveling toward Thailand moved slowly compared to waves traveling toward Sri Lanka.

For example, Indonesia's location as the closest country to the epicenter of the earthquake resulted in the quick arrival of the largest waves. In Indonesia, just 40 kilometers from the Earthquake epicenter, only a few minutes passed between the Earthquake and the arrival of waves ranging from 15–30 meters high. On average, flooding occurred anywhere from 500 meters to two kilometers inland, with the western coasts suffering the most extensive flooding. Additionally, the Tsunami pushed seawater as far as six kilometers inland along streams and rivers.[18]

In Thailand, the Tsunami arrived between 09:40–10:30 local time with waves that reached up to 10 meters in height, and flooded coastal areas up to three kilometers inland.

Inundation levels were greatest in areas of low lying land. In the Maldives, for instance, where 80% of the islands are less than one meter above sea level, 69 out of 199 (35%) inhabited islands were completely flooded, and 30 (15%) were half flooded. The waves reached the Maldives at 09:20 local time and ranged from one to five meters in height.

In addition to land elevation, absorbing capacities such as the presence or absence of natural barriers also influenced inundation levels. For instance, vegetated sand dunes almost completely blocked inundation in two Sri Lankan

Year	Location	M_t
1837	Valdivia, Chile	9.3
1841	Kamchatka	9.0
1868	Arica, Chile	9.0
1877	Iquique, Chile	9.0
1846	Aleutians	9.3
1952	Kamchatka	9.0
1957	Aleutians	9.0
1960	Chile	9.4
1964	Alaska	9.1
2004	Sumatra, Indonesia	9.1

Table 1—The 10 greatest recorded tsunamis, measured with tsunami magnitude (M_t = magnitude)

national parks, Yala and Bundala. The Tsunami waves reached into the parks only where the vegetated sand dunes were broken by river outlets. Similarly, mangroves and sea grass beds reduced inundation levels in the province of Phang Nga, Thailand.[18]

The Tsunami waves behaved uniquely in each of the coastal regions they struck, and should be considered a series of separate events. Each region has different topographical and environmental features that influenced wave height, type of wave (crashing, bore, or flood), speed, arrival times, and the distance the water penetrated inland (Table 2). Unfortunately, specific information about the event is not available for all locations.

Damage

Damage is harm or injury impairing the value or usefulness of something, or the health or normal function of persons. It is the negative result of the impact of an event on society and the environment. The severity of the damage depends on the magnitude of the event buffered by the resilience of the society and the environment impacted.[1] Structural damage may lead to diminished function in any component of a society. In the following description, damage to the components of society with a health impact is explored.

The damages that resulted from the Sumatra-Andaman Earthquake and Asian Tsunami were far from uniform. The varying magnitude with which the events struck from one country to the next offers a partial explanation, but to fully understand why the resulting damage differed from one country to the next, each country's capacity to absorb the impact of the event also must be taken into account. The first step toward understanding the relationships between the damage that resulted from these two events and regional absorbing capacities is to understand which damage can be attributed to these events. In order to accurately assess which damage can be attributed to the events, it is important to understand the pre-event status of the affected regions. Unfortunately, information on the pre-event status for some of the affected countries is limited. Pre-Tsunami data on conditions in Indonesia, for example, are incomplete and in some cases unavailable. In the regions of Indonesia most heavily impacted by the Tsunami, conflicts between separatist groups and the government have limited access for the last 20 years.

Similarly, political instability and insecurity also has limited data collection in Somalia. Even now that the Tsunami has struck and damage assessments are needed to facilitate relief and recovery efforts, violence continues to frustrate agency efforts to collect data. In January 2005, for example, the United Nations Environmental Programme (UNEP) received permission from Somali government officials to send a team of experts into the country to assess damage. However, due to security conditions, the UNEP was forced to abandon the mission.[18]

Damage to Health

Estimates on the number of people left dead, missing, and/or displaced vary considerably. The International Federation of the Red Cross and Red Crescent Socities, for instance, lists as many as an estimated 176,459 dead, 49,869 missing, and 1,723,543 displaced. In contrast, the USGS lists 280,000 dead, 14,100 missing, and 1,126,00 displaced. Deaths occurred in 12 countries surrounding the Indian Ocean basin,[16] but the death tolls included approximately 9,000 tourists (mostly European), thereby increasing the number of countries affected to at least 27 (Table 3).[28]

Socio-economic factors, gender, and age influenced death tolls within individual countries. The deaths attributed to the Sumatra-Andaman Earthquake and the Asian Tsunami, for instance, include a disproportionate number of women. Oxfam surveys in villages in India, Indonesia, and Sri Lanka found that the death toll among women was greater than the death toll among men. For example, in four villages in the Aceh Besar district, Oxfam found that three women died for every man that died. In the district's hardest-hit village, Kuala Cangkyo, 80% of the dead were female. Similar trends were found in villages it surveyed in India and Sri Lanka. The Tsunami had a particularly devastating impact on women in the Sri Lankan village of Dutchbar, where it is believed that at least 90% of the dead were female. The Tsunami struck the village at the hour when the women usually take their baths in the sea.

In proposing other possible reasons as to why more women died, Oxfam noted that women were more likely to be at home caring for children and the elderly, while the men were more likely to be safely at sea fishing or working inland. Oxfam also observed that women in the affected countries were less likely to have learned how to swim or climb trees and, therefore, were more likely to drown.[29] Similarly, eyewitness accounts gathered by the United Nations Children's Fund (UNICEF) indicate that children generally were too weak to hold on to fixed structures and resist the Tsunami's strong currents, making them particularly vulnerable to death and injury.[30]

Body recovery has been difficult, challenging efforts to assess death tolls accurately. The Tsunami distributed bodies over large areas, particularly those dragged out to sea. Approximately eight weeks after the Tsunami, for example, the bodies of Tsunami victims from Sri Lanka and Indonesia washed up on the shores of the Maldives. In addition, the large numbers of undocumented migrant workers in some of the affected regions has further complicated efforts to tally the number of people who are missing and may be dead.[31]

Country	Time elapsed from earthquake	UTC	Local Time	Wave height	Inland penetration
Indonesia	Minutes[18]	01:00–?[18]	08:00–?[18]	15–30m[18]	500m–2km[18]
Thailand	1h 40min–2h 30min[18]	02:40–03:30[18]	09:40–10:30[18]	5–20m[19]	2–3km[18]
Sri Lanka	1h 40min[18]	02:40[18]	08:40[18]	2–12m[20]	50m-->1km[21]
Maldives	3h[18]	04:20[18]	09:20[18]		
India (Tamilnadu)	3h 30min[22]	04:30 [22]	09:00[22]	2.8–3.9m[27]*	100m–2km[22]
India (Andaman and Nicobar islands)	minutes[22]	01:00-–?[22]	06:30–?[22]	1.5–7m[22]*	100–2km[22]
Malaysia	2–2h 30min[23]	03:00–03:30[23]	11:00–11:30[23]		
Myanmar	30–60min[23]	01:30–02:00[23]	08:00–09:30[23]	0.5–2.9m[19]	
Kenya	9–10h[23]	10:00–11:00[23]	13:00–14:00[23]	3m[25]*	45m[25]
Seychelles	7h[24]	08:00[24]	12:00[24]	2.5-4m[18]	
Somalia	7–8h[23]	08:00–09:00[23]	11:00[23]	4.5–9m[26]*	
Tanzania	10–11h[23]	11:00–12:00[23]	13:00–14:00[23]		
Bangladesh	2–2h 30min[23]	03:00–03:30[23]	09:00–09:30[23]		

Table 2—Tsunami arrival times, wave heights and inland penetration. *Note: These are run-up height estimates rather than wave height estimates. Run-up height is the height above sea level of a tsunami at the limit of inundation and is sometimes used to model tsunami heights when more direct data, such as water level measurements near shore, cannot be collected. (UTC = Universal Time Coordinate

Notably missing are data separating deaths due to the Sumatra-Andaman Earthquake verses deaths due to the resulting Tsunami. However, some insight may be gained by looking at the number of people who died due to the 28 March 2005 earthquake which also ruptured in the Sunda Trench. The 28 March earthquake measured 8.7 on the Richter scale and killed at least 1,300 people; 1,303 in Indonesia and 10 in Sri Lanka.[32] Because each whole number on the Richter scale represents a tenfold increase in measured amplitude, the 8.7 measurement indicates that the 28 March earthquake released a third of the energy released by the 9.0 Sumatra-Andaman Earthquake. Although many factors can contribute to the number of deaths that result from an earthquake, such as the time of day, length of shaking, etc., it is probably not unreasonable to assume that the number of deaths that resulted from the Sumatra-Andaman Earthquake is at least equal to the number of deaths in the 28 March earthquake.

Medical care

In many of the countries affected by the Tsunami, healthcare systems already were weak due to a shortage of both human and physical resources. According to the latest estimates recorded by the WHO, there only were 1.1 physicians per 10,000 people in Indonesia before the Tsunami and only 0.4 physicians per 10,000 people in Somalia.[33]

Healthcare systems in some of the hardest hit countries suffered significantly. In Indonesia only 93 of the country's 240 (39%) health clinics survived without damage. Of the less fortunate clinics, 30 (12.5%) were destroyed, 77 (32%) seriously damaged, and 40 (17%) suffered minor damage. Indonesia's already low number of healthcare personal (Table 4) also suffered in the wake of the tsunami. Of the 9,800 health personal before the Tsunami, nearly 10% have died or still are missing.[34] Additionally, the Tsunami-affected regions of Indonesia lost an estimated 30% of all midwives.[31]

Many healthcare systems were heavily burdened with patients for weeks after the Tsunami. The WHO estimates that 500,000 people in the countries affected by the tsunami required treatment for injuries.

Although the WHO worried about outbreaks of diseases such as salmonellosis, typhoid, cholera, hepatitis, shigellosis, and mosquito-borne diseases such as malaria and dengue, none of the predicted epidemic outbreaks occurred. Cases of hepatitis, malaria, measles, and watery diarrhea were reported, but in a 90-day assessment of the Tsunami-affected areas, the WHO did not recognize the number of cases reported as exceeding normal endemic levels.[35]

Water and sanitation

The regions affected by the Tsunami rely on a wide variety of water sources, including surface water, hand-dug wells, springs, boreholes, piped-in water systems, and tanker-supplied water. The most common sources of water in these regions, shallow wells and unprotected wells often become salienated or contaminated with fecal matter. However, because most of the households in the Tsunami-affected regions have continually dealt with unpredictable water supplies, many keep stores of water.[36]

When the Tsunami struck, it ruined fresh water supplies with seawater, sewage, and other wastes stirred by the waves. Shallow wells and groundwater on small islands proved particularly vulnerable. In the Maldives, where the tsunami destroyed nine out of ten toilets on some islands, sewage may have contaminated groundwater in more than 30 islands. In Sri Lanka, saltwater, and in some cases sewage, ruined >62,000 wells.

In Somalia, there is evidence that water supplies have been contaminated by nuclear and other hazardous wastes

Country	Population Mid-2005 (millions)*	Dead confirmed	Missing	Displaced	Homeless
Indonesia	221.9	128,645	37,063	532,898	n/a
Thailand	65.0	5,395	2,845	n/a	n/a
Sri Lanka	19.7	31,147	4,115	519,063	480,000
Maldives	0.3	82	26	21,663	n/a
India	1,103.6	10,749	5, 640	647,599	20,000
Malaysia	26.1	68	12	n/a	4,296
Myanmar	50.5	61	10	n/a	3,200
East Africa	96.3	312	158	2,320	n/a
Total	1583.4	176,459	49,869	1,723,543	507,496

Table 3—International Federation of the Red Cross and Red Crescent Societies. Note: East Africa includes Kenya, Madagascar, Seychelles, Somalia and Tanzania. Human toll estimates are not likely to vary much until a year after the disaster when most countries will officially declare the missing as dead.

Country	Hospital beds per 10,000	Year	Physicians per 10,000	Year	Nurses and mid-wives per 10,000	Year	Health work-ers per 10,000	Year
India	9	2003	5.9	2003	7.9	2003	13.8	2003
Indonesia	6.3[33]	1998	1.1	1998	4.9	2000	6	1998/00
Malaysia	19	2001	7	2000	18.1	2002	25.1	2002
Maldives	17	2000	8.4	2000	12.3	2000	20.7	2000
Myanmar	6	2000	3	2000	4.8	2000	7.8	2000
Somalia	4	1997	0.4	1997	2	1997	2.4	1997
Sri Lanka	22	1999	3.7	2002	7.9	2000	11.6	2000/02
Thailand	22	1999	3	1999	16.2	1999	19.2	1999

Table 4—Some pre-event indicators of the healthcare system in affected countries (Source: WHO, World Health Statistics 2005;[33] WHO Country Health Profile[37])

exported to Somalia by outside countries. The wastes have been dumped or buried near shore where they could have been stirred easily by the Tsunami.[18]

In the affected provinces of Indonesia, where rural water supplies suffered significantly, the Tsunami damaged or destroyed an estimated 60,000 wells and 15,000 hand pumps.[18] Four months after the Tsunami, a survey of 48 households in the Indonesian province of Aceh tested primary sources of drinking water. The survey found that more than 90% of the households were using sources contaminated with E. coli. The survey also took 43 samples from stored household water, and found that 22% contained levels of E. coli defined by the WHO as "intermediate risk" and 15% contained levels of E. coli defined by the WHO as "high risk".[36]

Discussion

The disasters created by the Sumatra-Andaman Earthquake and the subsequent Asian Tsunami of December 2004 were some of the worst in recorded history. This summary of the hazard, events, and a portion of the damage presents some of the information needed to analyze a disaster. However, knowledge about the hazard, event(s), and damage provides the cornerstone on which evaluations of preparedness and responses must be built. Research and analysis using the Utstein Framework provides a systematic way to evaluate a disaster and the consequences of a disaster.[1] This is essential to learning lessons about what can be done to enhance the absorbing capacity for future events.

The information available about the hazard may be the most complete. However, geological faults never are static, and therefore, information about them and the risks they pose require constant updating. For example, the release of stress in the area of the Earthquake may have placed stress elsewhere along the fault, creating a new hazard. Using the Utstein Framework makes information about the hazard useful in assessing risk of damage and/or a disaster, and in planning and preparedness activities.

The information available about the primary event of the Earthquake frequently focused on the epicenter of the event. However, sparse information is available on the effects distant from the epicenter of the Earthquake. Factors that influenced the Earthquake as it arrived in one region to the next are not well understood. For example, there is little geological research available on the sediments that comprise the affected regions, a major factor in determining how long and how hard an earthquake will shake.

In the Utstein Framework, determinants such as the local geology are used to describe the absorbing capacity of an area. For example, if a community is built on unstable soils, the buildings may be more vulnerable to shaking caused by earthquakes, and therefore, have a higher risk of the event of an earthquake causing damage.

Country	Population with reasonable access to safe drinking water (%)	Population with adequate exreta facilities (%)	Year
India	77.9	36	1998–99
Indonesia	80	70.5	1998
Maldives	76.5	85	2001
Myanmar	71.5	63.1	2000
Sri Lanka	75.4	72.6	2000
Thailand	92.7	97.7	2000

Table 5—Pre-event status of water and sanitation in some affected countries (Source: WHO Country Health Profiles)[37]

Similarly, information about the secondary event of the Tsunami was most complete for its behavior in deep ocean waters. However, information on how the Tsunami waves behaved at landfall offers only a narrow, clouded view of the severity of the event as it was experienced from one coast to the next.

The lack of specific information on how these events were experienced from one region to the next, cripples efforts to determine how much of the resulting damage can be attributed to the destructive force of the events and how much can be attributed to regional weaknesses in absorbing capacity. Differences in the absorbing capacities of the affected regions will remain obscured, if research does not first determine the severity of the events each region experienced.

The description of damage was the most inconsistent and incomplete. Without consistent and complete damage information for all of the affected regions, comparisons become difficult if not impossible. Damage information was frequently limited by regionally narrow information-gathering missions. Lack of resources may have prevented information-gathering organizations from conducting more comprehensive damage assessments. However, information on damages also revealed little coordination between information-gathering organizations. If there was a standardized approach to damage and needs assessments, information gathered by different organizations could have been pooled into an easily accessible database.

Damage information also was limited when the information was offered in a way that had little practical value. For example, the use of raw numbers, as opposed to percentages was a common in the damage assessments. Knowing that 35 wells were destroyed is more useful if we also know those 35 wells were responsible for providing 60% of the supply of potable water to the area. By adding the context of the pre-event condition, the information allows the assessor to more accurately predict the level of dysfunction as well as the needs in the area.

A cornerstone of the Utstein Framework is the use of the pre-event status of an affected society as a benchmark for assessing damage and loss of function as well as measuring progress of recovery efforts. Recognizing damage requires knowledge of the situation before the event occurred. It would be incorrect to attribute a contaminated well to the tsunami if in fact it had been contaminated many months prior to the event. Additionally, a disaster does not end until the affected society has returned to its pre-event status.

The Utstein Framework separates damage from the loss of function caused by damage. Damage-related dysfunction occurs when damage results in a loss of function. For example, if a laboratory suffers structural damage, it may not be able to perform diagnostic tests and, thereby, loses function compared to its pre-event level. Often, structural damage can be used to gauge dysfunction, but in many instances, functional indicators provide more useful and meaningful information. For example, in planning an immediate response, it is more important to know that 50% of patients wait >24 hours for medical care (a functional indicator), rather than the fact that one clinic was destroyed. However, knowing both the damage created and loss of function is ideal. Unfortunately, most assessments evaluated only damage; consequently a "loss of function" subheading is not included in this work.

Although information missing from gaps in the data presented in this paper may be available, it either was not readily accessible or not published when this paper was written. An easily accessible database with agreed upon indicators of pre-event status, damage, and dysfunction would facilitate future research and relief activities. Additionally, to completely describe the health damage that occurred in each affected country is beyond the scope of this work. The authors made every effort to provide enough information to give the reader an idea of the magnitude of the damage created by the event. However, individual papers using the Utstein Framework[1], with a single region or country as the sole topic are necessary.

Each country had a unique relationship to the hazard, experienced events of varying magnitude, and suffered different levels of damage. Therefore, a unique disaster occurred in each of the affected countries. Additionally, each country responded with a variety of coordination levels and control mechanisms. An analysis of each of the affected countries using consistent indicators would facilitate conclusions and build an evidence base about what needs to be done to prepare for future events.

Conclusions

The Conceptual Framework and terminology described in the *Disaster Health Management: Guidelines for Evaulation and Research in the Utstein Style* is a useful method for describing disasters and the communities affected by disasters. When disasters are forced into this framework, similiarities and differences regarding these disasters can be discovered. This information can be used to create best practice standards as well as contribute to preparedness planning. The full potential of using this framework is hampered by scattered information and a lack of standard indicators. Future accounts of disasters should use the *Utstein* guidelines in cataloging information.

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THE WORLD ASSOCIATION FOR DISASTER AND EMERGENCY MEDICINE

Requests Input and Expressions of Interest in the Development of Regional Chapters

The World Association for Disaster and Emergency Medicine (WADEM) is an international, humanitarian association dedicated to the improvement of disaster and emergency medicine. Its Board of Directors, pursuant to decisions of the Board made at Edinburgh, Scotland, May, 2005, hereby offer the designation of WADEM Chapters to nation-states, nation-state provinces or individual states, regional organizations and recognized healthcare societies of these entities who share the mission and dedication of WADEM.

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– Development and maintenance of evidence-based standards of emergency and disaster health care and provision of leadership concerning their integration into practice
– Coordination of data collection and provision of direction in the development of standardized disaster assessment and research and evaluation methodologies
– Encourage publications and presentation of evidence-based research findings in scientific publications, national, regional, and international conferences, and congresses
– Will foster and deliberately promote, whenever possible, the recognition of a regional, national, and or profession-specific knowlege base for the general WADEM membership. The WADEM agrees to recognize these advances in publications, conferences, congresses, task forces, and committees.

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