CHAPTER 7

Health-related impacts of Tsunami disasters

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Abstract

Tsunamis have the potential to cause an enormous impact upon the health of millions of people. During the last half of the twentieth century, more people were killed by tsunamis than by earthquakes [1]. Most recently, a major emergency response operation has been underway in the northeast Japan following a devastating tsunami triggered by the biggest earthquake on record in Japan. This natural disaster has been described as the most expensive in world history [2]. There are few resources in the public health literature that describe the characteristics and epidemiology of tsunami-related disasters, as a whole. This chapter reviews the phenomenology and impact of tsunamis as a significant public health hazard.

1 Background nature of tsunamis

1.1 Definition

The Japanese word tsunami translates in English to "harbor wave."

A tsunami is a series of ocean waves generated by any disturbance that displaces a large water mass [3]. About 90–95% of tsunamis are caused by large earthquakes (usually Richter magnitude 6.5 or greater); the remainders are primarily due to volcanic eruptions (like the eruption of Mt. Krakatau in 1883) or landslides (like the 1998 Papua New Guinea tsunami generated by a submarine landslide). There are also composite events such as the 1946 subduction earthquake in the Aleutian Islands that triggered a landslide-generated tsunami killing

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159 people in Hawaii [4]. Prehistoric geological evidence has also implicated meteorites or comet impacts as a rare cause of tsunami (the most notable is located near the Yucatán Peninsula in the Gulf of Mexico) [5].

To understand tsunamis, it is helpful to distinguish them from wind-generated waves or tides. Wind blowing across the ocean deforms the surface into relatively short waves to create currents restricted to a shallow surface layer. Strong gales are able to whip up waves 100 ft, (30 m), or higher in the open ocean but even these do not move deep water [6]. Wind-generated surface waves typically have a high frequency and short wavelength (distance between wave crests) as compared to the extremely low frequency and long wavelength of tsunami waves. Tsunamis often are called by the popular name, "tidal waves," but this is a misnomer. They are not caused by the tidal action of the moon and sun like the regular ocean tides. Rather they are long water waves generated by sudden displacement of the earth under water.

1.2 Causes of tsunamis

The type of earthquake is as important as its strength in determining whether or not a tsunami will occur. The earth's crust is made up of a "jigsaw puzzle" of tectonic plates that abut and move against each other. Subduction zones are faults in the earth's crust in which one tectonic plate overrides another. Movement along this type of fault typically produces the vertical land movement necessary to generate a tsunami. Subduction earthquakes can impart a vertical displacement on the earth's surface that is hundreds of miles long and thus displace billions of tons of water. Earthquakes that produce largely horizontal movement (i.e., the San Andreas Fault in California, US) do not typically generate tsunamis. In addition, the causative earthquake must occur at relatively shallow, (<31 miles or 50 km), depths underground in order to efficiently transfer ground energy to the water above. Great trans-ocean tsunamis are typically caused by massive subduction earthquakes whose rupture zones extend several hundreds of kilometers along the trench. These earthquake-generated tsunamis spread outwards in all directions from the point of origin [7]. In comparison, tsunamis triggered by submarine landslides produce a relatively narrow radiation pattern resulting in a focused beam of energy with the potential of also reaching far afield [4].

Giant submarine landslides (and impacts from extra-terrestrial sources such as comets and meteors) have the potential to create extremely large waves referred to as mega-tsunamis. At least 100 mega-tsunamis in different parts of the world have been recorded in the past 2000 years according to interpretation of the sedimentologic and geomorphic imprints left by these events [8]. Mega-tsunamis produced by giant submarine landslides were first proposed for Hawaii and have since been implicated globally on other oceanic islands along with continental margins [9]. For instance, marine deposits in the Hawaiian Islands that lie up to 1230 ft (375 m) above the sea level on the island of Lanai have been attributed to the action of a mega-tsunami-generated by giant submarine landslides from Mauna Loa volcano on the big island of Hawaii [10]. Giant wave deposits found in the Bahamas coincide with a prehistoric volcano collapse in La Palma, Canary Islands [11].

1.3 The physics of tsunami phenomenon

Regardless of their origin, tsunamis evolve through the three overlapping but quite distinct physical processes: generation by any force that disturbs the water column, propagation from deeper water near the source to shallow coastal areas, and, finally, inundation of the dry land.

Generation is the process by which a seafloor disturbance, such as movement along a fault, reshapes the sea surface into a tsunami. Vertical displacement of the ocean floor results in a transfer of seismic energy to the entire column of water above. Propagation of the tsunami transports seismic energy away from the earthquake site through the water just as shaking moves the energy through the earth during an earthquake. Once the tsunami is generated, a series of extremely low frequency, long wavelength, (~186 miles or 300 km), waves are propagated in an expanding radius from the area of displacement traveling at a speed proportional to the square root of the depth of water reaching up to 600 miles (965 km) per hour in the deep ocean.

Because the energy is spread throughout such a large volume in deep water and have such a long wavelength between crests, tsunamis may be only a few feet (<1 m) high in the mid ocean, making them capable of passing under ocean-going ships with little disturbance or detection. The physical dynamics of the fluid pressure wave allow it to travel great distances with very little loss of energy. For example, a subduction earthquake occurring on January 26, 1700 at the Cascadia subduction zone encompassing western Washington and Oregon generated a tsunami that destroyed the island of Honshu, Japan [12, 13].

The dependence of wave speed on water depth also causes individual waves to slow down as they approach shallow water, so they begin to overtake one another decreasing the distance between them in a process called shoaling. Refraction of the wave off the seafloor and shoaling focuses the same amount of energy into a smaller volume of water creating higher waves and faster currents as the tsunami reaches land [6].

The last stage is inundation in which a tsunami may run ashore as a breaking wave, a wall of water or a tide-like flood is perhaps most difficult to model. Vertical run-up typically takes only 2–3 m to cause damage along the shoreline. Horizontal inundation, if unimpeded by coastal cliffs or other steep typography, can penetrate hundreds perhaps even thousands of meters inland.

Vertical run-up of a tsunami is usually 10–50 ft (3–15 m) high. Wave heights averaged 80 ft (24 m) above the sea level along the western coastline of Sumatra during inundation of the 2004 Indian Ocean tsunami earthquake [14]. A 230 ft (70 m) wave was recorded following the 1964 Alaska earthquake [15]. Extremely rare mega-tsunamis produced by giant submarine landslides have been implicated globally [9]. The highest mega-tsunami wave ever witnessed occurred at Lituya Bay, Alaska in 1950. It was triggered by an 8.0 magnitude earthquake-induced landslide and reached the height of 1720 ft (524 m) above the shoreline, (three stories higher than the former World Trade Center of New York City) [3].

As the tsunami enters shallow water near coastlines, the kinetic energy previously spread throughout the large volume of ocean deep ocean water becomes concentrated to a much smaller volume of water, resulting in a tremendous destructive potential as it inundates the land. Successive crests may arrive to shore at period intervals of every 10–45 min. This phenomenon is particularly problematic when responders attempt to rescue victims from the water after the first wave, only to become victimized by subsequent waves themselves. A single tsunami event may comprise up to 12 wave crests. Prior to inundation of the wave crest, the sea often appears to recede for an unusually far distance.

During 1960, Chilean tsunami that struck Hilo, Hawaii, this phenomenon tended to attract more people to the shoreline and into the ocean itself where they were then caught up in the oncoming wave crest. One village in Papua New Guinea reportedly recognized this as a sign of pending tsunami and took protective actions for shoreline evacuation. In Simelue, Indonesia, an old song about moving to high ground when the earth shakes is reported to have saved lives and resulted in a relatively low death rate compared to neighboring Sumatra (which was farther from the quake epicenter).

2 Scope and relative importance of tsunamis

Tsunamis have occurred in all the oceans and in the Mediterranean Sea. About 90–95% of the world's tsunamis have occurred in the Pacific Ocean due to its relatively large size and its bordering "Ring of Fire" comprised of major tectonic subduction fault zones. Great trans-Pacific tsunamis are typically caused by massive earthquakes located at these subduction zones and occur at an interval of about once a decade [1].

Since 1900, there have been 52 tsunami events worldwide that resulted in at least one fatality [16]. During the 1990s, a total of 82 tsunamis were reported worldwide – a rate much higher than the historical average of 57 per decade (likely a result of better reporting) [6]. During the past decade since 1992, 14 tsunami events have caused over 182,059 deaths, and at least $USD 267 billion in damage [16] (see Table 1).

The 2004 Indian Ocean tsunami alone killed 165,708 people (91% of all tsunami deaths since 1990) and directly affected two million people in 12 nations [16]. WHO has estimated the number of injuries that required treatment as result of the 2004 Indian Ocean tsunami at about 500,000 [17].

In a 100-year period from 1895 to 1995, there were 454 tsunamis recorded in the Pacific Ocean, the deadliest 94 killed over 51,000 people [3]. Over the past Century in Japan, approximately 15% of 150 tsunamis were damaging or fatal. More than half of the 34 tsunamis that struck Indonesia in the past 100 years were damaging or fatal. More than 200 tsunamis are known to have affected the United States since the time of first written records. Total damage is estimated at half $1 billion and 470 casualties, primarily in Alaska and Hawaii [3]. Hawaii, because of its mid-ocean location, is especially vulnerable to such Pacific wide tsunamis. Twelve damaging tsunamis have struck Hawaii since 1895. In the most destructive,

Table 1: Fatal tsunami/earthquake disasters 1992–2011.

Year	Location	Estimated damage ($USD million)	Fatalities
1992	Nicaragua	25	179
1992	Indonesia	100	2500
1993	Japan	1000	239
1994	Indonesia	2.2	239
1994	Philippines	3.7	81
1995	Mexico	21.1	6
1996	Indonesia	1.2	9
1996	Peru	Not available	7
1996	Indonesia	4.2	161
1998	Papua New Guinea	Not available	2182
2004	Indian Ocean	4500	165,708
2009	South Pacific	160	186
2010	Chile	30,000	562
2011	Japan	235,000	21,911 (as of 3/21/11)
1990–2011	Totals	267,820.4	182,059

Source: Centre for Research on the Epidemiology of Disasters [16].

159 people died there in 1946 from killer waves that were generated almost 2300 miles (3700 km) away in Alaska's Aleutian Islands [3].

The Alaska Aleutian subduction zone poses an immediate tsunami threat to the western coast of the United States. Another major tsunami threat is located off the coast of Washington state or Oregon and northern California, known as the Cascadia subduction zone. The probability of a major earthquake occurrence before 2045 is estimated at 35% along this zone. A Cascadia-born tsunami disaster could cost the region between $1.25 and $6.25 billion [6]. A mega-tsunami resulting from the collapse of La Palma, Canary Islands could strike the Caribbean, Florida and the rest of the US eastern seaboard with a vertical run up of 164 ft, (50 m), high and a horizontal inundation of 12 miles (20 km) inland [11].

The human health effects of tsunamis cannot be understated. In addition to the public health and medical consequences of these disasters, the socioeconomic, cultural, and psychological impact of tsunamis have had an enormous and long-lasting impact throughout the world and a direct effect upon human development in general. Total damage and losses after the 2004 Indian Ocean tsunami are estimated at $USD 4.5–7 billion. One hundred seventy four million dollars of those losses were incurred by the health care system with an estimated health sector reconstruction cost in the order of $USD 107 million [17]. The World Bank has estimated that damages due to the 2011 Japan tsunami may range from $USD 122 to 265 billion, (2.5–4% of Japan's GDP) [2].

3 Factors that contribute to the tsunami problem

Despite the remarkable advances in tsunami monitoring and early warning, death tolls remain remarkably high. The high death tolls are partly due to increases in coastal populations and high-risk land use patterns. Settlement patterns increasingly place dense populations in close proximity to the tsunami hazard. In addition, the overwhelming majority of coastal communities located in the tsunami-prone Pacific basin have no direct linkage to the multimillion dollar Tsunami Warning System (TWS).

Most nations at risk lack the resources necessary to effectively warn and evacuate coastal populations. After the Chilean earthquake of 2010, experts have debated how much emergency-response planners should rely on tsunami forecasts [18]. Difficulties in modeling and predicting the vertical run up of tsunamis as they approach the shore also contribute to a degree of uncertainty in advance warning that may affect the public's perception of risk. A false alarm that triggered the evacuation of Honolulu on May 7, 1986, cost Hawaii more than $30 million in lost salaries and business revenues [6]. Even the most reliable warning is ineffective if people do not respond appropriately. Community education is therefore perhaps the most important aspect of any tsunami mitigation program.

4 Factors affecting tsunami occurrence and severity

The effects of the tsunami may vary with factors including: proximity to the earthquake epicenter; physical geography of the region; the force of the waves when they hit the shore; and the extent to which the waves penetrate the shoreline. Proximity to the epicenter of the earthquake or submarine landslide is directly associated with an increased severity due to the amount of seismic energy transferred during vertical run up and horizontal inundation. During 2004 Indian Ocean tsunami, Indonesia (the closest land to the epicenter) suffered the most severe tsunami strikes, followed by Andaman Nicobar, Thailand, Maldives, Sri Lanka, India, and eastern Africa as distance from the epicenter increased.

Refraction by bumps, grooves, and troughs on the seafloor can shift the wave direction, especially as it travels into shallow water. In particular, wave fronts tend to align parallel to the shorelines with a wraparound protruding head land before smashing into it with greatly focused incident energy [6]. The author observed this phenomenon as particularly evident in the total destruction of the cities of Banda Aceh, and Calang, Indonesia where the waves entered and exited the headlands from both sides of the peninsula-like headland. After the 1946, Aleutian Island earthquake vertical run ups in the Marquesas (4660 miles or 7500 km from the source), were larger than in Hawaii (2300 miles or 3700 km closer) due to a funneling effect in narrow valleys [4].

The effects of tsunamis on coastal areas are characterized by the maximum destructive force of the water's edge. Damage farther inland is potentially high even though the force of the wave has diminished because of the floating debris that batters the inland installations. Low-lying coastal areas and coral atolls (such as the Maldives) also suffer an increased severity of destruction.

5 Public health impact: historical perspective

There is strong evidence that a magnitude 8 earthquake generated along the Cascadia fault zone shook the northwest coast of the United States causing a tidal wave that hit the Japanese island of Honshu on January 26, 1700 [12]. It is believed a tsunami killed more than 30,000 people within 75 miles (120 km) of the catastrophic eruption at Krakatau, Indonesia volcano in 1883. Of the 12 most deadly tsunamis during 1900–2011, four occurred in Japan and four were in Indonesia, with all but two originating in the Pacific Ocean. Most resulted in several hundred to several thousand deaths per event [16].

The 1946, Aleutian island tsunami was the most destructive in the history of the Hawaiian Islands. More than 150 persons were killed, while damage to property amounted to $26 million. The United States reacted to this disaster by setting up the Pacific Tsunami Warning Center in Hawaii in 1948 [6].

Earthquake-triggered landslides have the potential to create tsunamis much larger than expected for the size of the earthquake. In 1998, the Papua New Guinea tsunami generated waves up to 50 ft (15 m) high, killing 2200 people after a magnitude 7.1 earthquake. Two rare landslides in the western Atlantic also fuel the tsunami concern in the eastern United states. In 1929, an earthquake-triggered landslide off Newfoundland's grand Banks generated a tsunami that killed 51 people [19].

The single largest tsunami disaster in recorded history occurred in the Indian Ocean on December 26, 2004 along the Andaman Nicobar fault zone. The tsunami killed more than 300,000 people and displaced 2 million persons in 12 nations. Most recently, a powerful 9.0-magnitude earthquake hit Japan on March 11, 2011, unleashing massive tsunami waves that resulted in widespread damage and destruction. According to the Government of Japan as of March 21, at least 21,911 were dead and missing and 2644 injured [20].

6 Factors influencing mortality and morbidity

6.1 Mortality trends

The vast majority of tsunami-related deaths occur immediately [1]. In a large tsunami, deaths frequently exceed the number of injured [1, 21]. The number of tsunami-related deaths exceeded the number of injuries caused by the 2011 Japan tsunami by a ratio of nearly 7:1 [20]. The vast majority of those causalities were sustained as a result of the tsunami rather than the earthquake. Average death rates are believed to be 50% for the population affected by tsunami [1]. The 30,000 inhabitants of Calang in Aceh province, Indonesia suffered an estimated 70% mortality rate during inundation of the December 26, 2004, tsunami [22].

Most tsunami deaths ultimately result from drowning. However, the tsunami does not consist only of water. It also contains a great amount of very heavy debris traveling with tremendous momentum. The 2004 Indian Ocean tsunami (and associated debris) was estimated to have travelled at 30 miles per hour, (48 km/h), when on shore in Aceh province, Indonesia.

Deaths from tsunami injuries occur in three phases. Victims usually succumb to injuries that are incompatible with life (drowning, severe head, chest, and spine injuries) within the first few minutes. Then immediate complications set in over the next few minutes to hours (such as bleeding, lung collapse, and blood clots in the lung). Finally, these immediate causes of death are followed by delayed complications over the coming days that are mostly associated with infectious disease (such as wound infections and aspiration pneumonia) [23, 24].

According to a survey recently carried out by Oxfam, four times as many women than men were killed in the tsunami-affected areas of Indonesia, Sri Lanka, and India [25]. One study of disaster-related mortality in Sri Lanka observed a higher mortality rate among females, children and the elderly. Other risk factors included: being indoors at the time of the tsunami; the degree of house destruction; and fishing as an occupation [26].

6.2 Tsunami-associated illness and injury

A tsunami directly injures the victims by the mechanism of blunt trauma and penetrating injury [26]. People are bludgeoned by concrete slabs and felled trees, stabbed by jagged sheets of metal and glass, tangled up in manacles of wire, and impaled onto tree limbs and bamboo. Soil, small pieces of wood, glass, and metal in the contaminated saltwater penetrate the soft tissues of the body at high velocity. The predominant pattern of injury comprised multiple large-scale soft tissue wounds of lower extremities and open fractures [26]. Wound contamination was also a major clinical problem [24].

When the 2004 Indian Ocean tsunami hit the western coast of southern Thailand, 6 to 8 huge waves with a height of 15–22 ft (5–7 m) destroyed almost everything along the beach and inundated areas more than 984 ft (300 m) from the seashore. Most of the survivors had minimal to moderate injuries to the body and extremities [27].

No survivor of the Papua New Guinea tsunami was found to have head, spine, thorax, or abdomen injuries, implying that survival of these life-threatening injuries was virtually impossible in that remote setting with delayed resuscitative and surgical care [26]. Bone fractures, soft tissue injuries, and near-drowning were the most common conditions reported among survivors in both the Papua New Guinea and the Indian Ocean tsunamis [27–30].

6.3 Infectious diseases

The role of active case finding and generous availability of health services surely played a role in the noted eight-fold increase of acute respiratory infections in

Aceh province, but it can generally be agreed that acute respiratory infection did increase substantially following the 2004 tsunami. Cases of acute respiratory infections decreased significantly after the first 5 weeks suggesting that the largest caseload occurs within a month after the disaster event, and is related to tsunami-induced near-drowning as a major causative factor [31].

Near-drowning is common in tsunamis and is frequently associated with aspiration pneumonia or "tsunami lung," a necrotizing pneumonia notable for flora commonly associated with sea water near drowning (e.g. *Aeromonas* and *Pseudomonas* species). However, after the Indian Ocean tsunami, cultures from the upper respiratory tract specimens also grew an unusually high rate of relatively uncommon pathogens that are not associated with sea water aspiration (such as multiple-resistant *Acinetobacter baumanii*, methicillin-resistant *Staphylococcus aureus*, *Stenotrophomonas maltophilia*, *Burkholderia pseudomallei*, and Candida albicans) [24, 28, 32].

After the 2011 Japanese, tsunami physicians reported a combined pulmonary infection of the Legionella and multiple antibiotic resistant *Escherichia coli* [33]. There were also other case reports of tsunami lung associated with multiple uncommon pathogens (including *Stenotrophus maltophilia, Legionaella pneumophilia, Burkholderia cepacia, and Pseudomonas aeruginosa*) [34]. There was also a case of pleural empyema reportedly associated with the patient's aspiration of a small pine tree branch [35]. One patient that survived near-drowning was diagnosed with *E. coli* pneumonia in combination with a fungal sinusitis and meningitis [36].

In addition to the aspiration pneumonia described as "tsunami lung," the rate of hospitalizations for infectious disease doubled during the one month following after the 2011 Japan tsunami as compared to the same period during 2010. Community-acquired pneumonia (caused by *Streptococcus pneumoniae, Moraxella catarrhalis, and Haemophilus influenza*) comprised 43% of those hospital admissions for infectious disease during that period [37].

Melioidosis, a serious infection caused by *B. pseudomallei*, is reported most commonly in Southeast Asia and northern Australia. The infection is acquired by contamination of breaks in the skin or by inhalation. Several cohorts of patients in southeast Thailand and the Phuket area was diagnosed with melioidosis after aspiration related to the Indian Ocean tsunami. Immunocompromise was an associated risk factor as would be expected [23, 38, 39].

Tsunami wounds are inevitably contaminated with soil, debris, and foreign bodies. Wound infections were common after the 2004 Indian Ocean tsunami and comprised 16.9% of all diagnoses by January 10 at the International Committee of the Red Cross (ICRC) field hospital in Calang, Indonesia) [22] and 15% of all consultations at the ICRC field hospital in Banda Aceh [31]. Subcutaneous tissue infection comprised 12% of hospital admissions for infectious disease during the month following the 2011 Japan tsunami [37].

Similar to acute respiratory infections, wound infections also frequently involved multiple, relatively uncommon pathogens (such as *P. Aeruginosa*, *Stenotrophomonas maltophilia*, and *Klebsiella pneumonia*) [24, 30, 40]. Acute open marine trauma is not infrequently associated with subsequent infection [24]. However cultures also indicated significant coexistent contamination with highly resistant species uncommon to aquatic surroundings (such as multiple-resistant *A. baumannii*, extended-spectrum beta lactamase producing *E. coli*, methicillin-resistant *Staphylococcus aureus* and *Candida* species). One case report described multifocal cutaneous mucormycosis complicating polymicrobial wound infections in a tsunami survivor from Sri Lanka [40].

As was also the case in populations affected by hurricanes Andrew and Iniki, tetanus cases increased after the 2004 Indian Ocean tsunami and 2011 Japanese tsunami as result of soil-contaminated injuries sustained at the time of impact [31, 37]. The number of cases then returned to the baseline within 1 month of the event, signifying that all cases were the result of wound contamination sustained during the tsunami event itself [31].

The correct identification of pathogens and their antimicrobial susceptibility is essential to reduce mortality, especially in the case of wound infections and unusual respiratory infections after tsunami. Therefore, sufficient diagnostic and confirmation capacities such as radiology and laboratory services should be made available. For this reason, emergency medical teams should be aware of resistance patterns in the target areas before or shortly after arrival to respond appropriately to the situation. Emergency health kits should include medications that offer appropriate broad-spectrum antimicrobial coverage for such infections as those that would be expected after tsunami.

Contrary to initial concerns for outbreaks of malaria, measles, cholera, and dengue, [41–46], the Indian Ocean tsunami (like the overwhelming majority of all previous seismic disasters) was not associated with epidemics of infectious disease [31].

Despite reports of a significant risk of vector abundance with enhanced transmission potential [45] no increases in cases for malaria or dengue were noted in any nation of the tsunami-affected regions of Southeast Asia [31] Ironically, the post-tsunami monthly incidence of malaria in Aceh province, Indonesia was more than 10 times lower than the comparable monthly rate over the last five years prior to the 2004 tsunami [31]. Experience has shown that these diseases, however commonly believed, are not always a priority immediately after any natural disaster [31].

6.4 Worsening of chronic diseases

As is the case with most disasters, tsunamis have been reported to also exacerbate pre-existing chronic diseases among the population. After the Japan tsunami, the number of patients with acute decompensated heart failure nearly doubled as compared to the predisaster. This impact was found to peak at 3 to 4 weeks after the disaster. It is thought to be associated with stress, sudden changes in activities of daily life, diet and disruption of availability of prescribed medications [47]. Other studies revealed poor management of diabetes and hypertension among patients that were displaced by the tsunami (presumably many of the same reasons as for the heart failure) [48, 49]. One report described a high prevalence of deep vein thrombosis in disaster shelters were set up in flooded areas after the tsunami. This was largely attributed to inactivity, as well as dehydration, and gastrointestinal illness brought on by inadequate water and sanitation in these shelters [50]. The incidence of peptic ulcers was 1.5-fold increased, and in particular, the incidence of hemorrhagic ulcers was 2.2-fold increased [51].

6.5 Psychosocial consequences

Behavioral health effects are among the most chronic and debilitating outcomes of natural disasters, including tsunamis [52, 53]. Clinical symptoms of posttraumatic psychological stress response have been widely noted among tsunami survivors and relatives [24].

Among survivors of the tsunami in southern Thailand, elevated rates of symptoms of posttraumatic stress disorder (PTSD), anxiety, and depression among adults were reported 8 weeks after the disaster with higher rates for anxiety and depression than PTSD symptoms. Nine months after the disaster, the rates of those reporting the symptoms decreased but were still elevated [54].

Prevalence of PTSD symptoms among children in displacement camps of southern Thailand were elevated as compared to nonaffected villages. After 9 months, the prevalence of PTSD symptoms among children's and camps had not significantly decreased [55].

The monumental devastation of the December 2004 Indian Ocean tsunami also prompted a meta-analysis of the psychosocial consequences of natural disasters in developing countries versus developed countries. A much higher proportion of the population in developing nations sustained severe loss and extreme trauma and experiences that constitute clinically significant distress as compared to developed nations (for not only tsunamis, but all natural disasters in general) [53, 56]. Posttraumatic stress and psychological changes were reported to increase along with stress-related hormones among populations affected by the Japan tsunami and earthquake [57]. This was also exacerbated by the potential for radiological exposure due to the Fukushima nuclear incident. High levels of anxiety distress and anger were noted among British nationals in Japan following the Fukushima nuclear accident [58]. As a result of concerns for potential radioactive contamination among international travelers, some governments established screening protocols for detection of external radioactive material contamination at points of entry. Despite resource intensive screening, only 3 out of 543,000 travelers screened were found to have measurable contamination [59].

7 Conclusion

Tsunamis represent a significant public health hazard for coastal populations located near tectonic subduction zones. The public health impacts of tsunamis are well known and predictable. The overwhelmingly most significant health impact is that of mass fatalities due to drowning. Other health impacts are related to traumatic injuries, unusual respiratory and skin infections, disruption of the public health infrastructure, worsening of chronic diseases, population displacement, and psychological stress.

Disclaimer

The material in this chapter reflects solely the views of the author. It does not necessarily reflect the policies or recommendations of the Centers for Disease Control and Prevention or the US Department of Health and Human Services.

References

[1] McCarty, D., Tsunamis. *Disaster Medicine*, eds. D. Hogan & J. Burstein, Philadelphia, PA: Lippincott, William and Wilkins; New York, NY, pp. 229–234, 2002.

[2] World Bank. The recent earthquake and tsunami in Japan: implications for East Asia. World Bank East Asia and Pacific Economic Update 2011, vol. 1. Available at http://siteresources.worldbank.org/INTEAPHALFYEARLYUPDATE/Resources/550192-1300567391916/EAP_Update_March2011_japan.pdf?cid=EXTEAPMonth1 (accessed 22 March 2011).

[3] Boyarsky, I. & Shneiderman, A., Natural and hybrid disasters – causes, effects and management. *Topics in Emergency Medicine*, **24(3)**, pp. 1–25, 2002.

[4] Fryer, G., Watts, P. & Pratson, L., Source of the great tsunami of 1 April 1946: a landslide in the upper Aleutian forearc. *Marine Geology*, **204**, pp. 201–218, 2003.

[5] Bolt, B.A., *Earthquakes: a Primer*. WH Freeman: San Francisco, 1978.

[6] Gonzalez, F., Tsunami. *Scientific American*, **280(5)**, pp. 57–65, 1999.

[7] Perez, E. & Thompson, P., Natural hazards: causes and effects. *Prehospital and Disaster Medicine*, **10(1)**, pp. 66–70, 2005.

[8] Scheffers, A. & Kelletat, D., Sedimentologic and geomorphologic tsunami imprints worldwide – a review. *Earth Science Review*, **63(1–2)**, pp. 83–92, 2003.

[9] McMurtry, G., Watts, P., Fryer, G., Smith, J. & Imamura, F., Giant landslides, mega-tsunamis and paleo-sea level in the Hawaiian Islands. *Marine Geology*, **203**, pp. 219–233, 2004.

[10] Moore, J.G. & Moore, G.W., Deposit from a giant wave on the island of Lanai, Hawaii. *Science*, **226**, pp. 1312–1315, 1984.

[11] Marshall, T., The drowning wave. *New scientist*, **2259**, pp. 26–31, 7 October 2000.

[12] Anonymous. Linking trees to tsunamis. *Science*, **278**, p. 1021, 7 November 1997.

[13] Satake, K., Wang, K. & Atwater, B., Fault slip and seismic moment of the 1700 Cascadia earthquake inferred from Japanese tsunami descriptions. *Journal of Geophysical Research*, 2003.

[14] Paulson, T., New findings super-size our tsunami threat. *Seattle Post Intelligence*. 7 February 2005. Available at http://seattlepi.nwsource.com/local/211012_tsunamiscience07.html (accessed 22 March 2011).

[15] Alaska Division of Emergency Services. *Tsunami! The Great Waves in Alaska*. Alaska Division of Emergency Services: Anchorage, AK, 1992.

[16] Centre for Research on the Epidemiology of Disasters (CRED). *EM-DAT, the International Disaster Database*, 2011. Available at http://www.emdat.be/result-disaster-profiles?disgroup=natural&period=1900%242011&dis_type=Earthquake+%28seismic+activity%29&Submit=Display+Disaster+Profile (accessed 22 March 2011).

[17] Carballo, M., Daita, S. & Hernandez, M., Impact of the tsunami on healthcare systems. *Journal of the Royal Society of Medicine*, **98**, pp. 390–395, 2005.

[18] Schiermeier, Q., Model response to Chile quake? *Nature*, **464(7285)**, pp. 14–5, 2010

[19] Simpson, S. Killer waves on the East Coast? *Scientific American*, **283(4)**, pp. 16–17, 2000.

[20] United Nations Office for the Coordination of Humanitarian Affairs (OCHA). *Japan Earthquake & Tsunami*, Situation report No. 10. 2011, available at http://www.reliefweb.int/rw/rwb.nsf/db900sid/SMDL-8F6DN8?OpenDocument&emid=EQ-2011-000028-JPN (accessed 22 March 2011).

[21] Calder, J. & Mannion, S., Orthopedics in Sri Lanka post-tsunami. *Journal of Bone and Joint Surgery*, **87-B(6)**, pp. 759–761, 2005.

[22] Brennan, R. & Rimba, K., Rapid health assessment in Aceh Jaya District, Indonesia, following the December 26 tsunami. *Emergency Medicine Australasia*, **17**, pp. 341–350, 2005.

[23] Kongsaengdao, S. Treatment of Survivors after the tsunami. *New England Journal of Medicine*, **25(352)**, pp. 2654–2655, 2005.

[24] Maegele, M., Gregor, S. & Steinhausen, E., The long-distance tertiary air transfer and care of tsunami victims: injury pattern and microbial and psychological aspects. *Critical Care Medicine*, **33(5)**, pp. 1143–1144, 2005.

[25] Oxfam International. *The Tsunami's Impact on Women*. Oxfam briefing notes. 2005, available at http://publications.oxfam.org.uk/display.asp?k=002P0179&keyword=tsunami+impact+on+women&sort=SORT_DATE%2Fd&m=2&dc=2 (accessed 22 March 2011.

[26] Nishikiori, N., Abe, T., Costa, D.G., Dharmaratne, S.D., Kunii, O. & Moji, K., Who died as a result of the tsunami? Risk factors of mortality among internally displaced persons in Sri Lanka: a retrospective cohort analysis. *BMC Public Health*, **6**, p. 73, 2006.

[27] Taylor, P., Emonson, D. & Schlimmer, J., Operation Shaddock-the Australian Defence Force response to the tsunami disaster in Papua New Guinea. *Medical Journal of Australia*, **169**, pp. 602–606, 1998.

[28] Watcharong, C., Chuckpaiwong, B. & Mahaisavariya, B., Orthopaedic trauma following tsunami: experience from Phang Nga, Thailand. *Journal of Orthopaedic Surgery*, **13(1)**, pp. 1–2, 2005.

[29] Holian, A. & Keith, P., Orthopedic surgery after Aitape tsunami. *Medical Journal of Australia*, **169**, pp. 606–609, 1998.

[30] Lim, P., Wound infections in tsunami survivors. *Annals of the Academy of Medicine, Singapore*, **34(9)**, pp. 582–585, 2005.

[31] Guha-Sapir, D. & van Panhuis, W., *The Andaman Nicobar Earthquake and Tsunami 2004: Impact on Diseases in Indonesia*. Brussels, Belgium: Centre for Research on the Epidemiology of Disasters, 2005.

[32] Allworth, A., Tsunami lung: a necrotizing pneumonia in survivors of the Asian tsunami. *Medical Journal of Australia*, **182(7)**, p. 364, 2005.

[33] Ebisawa, K., Yamada, N., Okada, S., Suzuki, Y., Satoh, A., Kobayashi, M. & Morikawa, N., Combined Legionella and Escherichia coli lung infection after a tsunami disaster. *Internal Medicine*, **50(19)**, pp. 2233-6, 2011.

[34] Inoue, Y., Fujino, Y., Onodera, M., Kikuchi, S., Shozushima, T., Ogino, N., Mori, K., Oikawa, H., Koeda, Y., Ueda, H., Takahashi, T., Terui, K., Nakadate, T., Aoki, H. & Endo, S., Tsunami lung. *Journal of Anesthesia*, **26(2)**, pp. 246–249, 2012.

[35] Ota, H. & Kawai, H., An unusual case of pleural empyema in a tsunami survivor. *Asian Cardiovascular and Thoracic Annals*, **20(3)**, pp. 344–346, 2012.

[36] Igusa, R., Narumi, S., Murakami, K., Kitawaki, Y., Tamii, T., Kato, M., Sato, M., Tsuboi, M. & Ota, K., Escherichia coli pneumonia in combination with fungal sinusitis and meningitis in a tsunami survivor after the Great East Japan Earthquake. *The Tohoku Journal of Experimental Medicine*, **227(3)**, pp. 179–184, 2012.

[37] Aoyagi, T., Yamada, M., Kunishima, H., Tokuda, K., Yano, H., Ishibashi, N., Hatta, M., Endo, S., Arai, K., Inomata, S., Gu, Y., Kanamori, H., Kitagawa, M., Hirakata, Y. & Kaku, M., Characteristics of infectious diseases in hospitalized patients during the early phase after the 2011 Great East Japan earthquake: pneumonia as a significant reason for hospital care. *Chest*, **143(2)**, pp. 349–356, 2013

[38] Chierakul, W., Winothai, W., Wattanawaitunechai, C., Wuthiekanun, V., Rugtaengan, T., Rattanalertnavee, J., Jitpratoom, P., Chaowagul, W., Singhasivanon, P., White, N.J., Day, N.P. & Peacock, S.J., Melioidososis in six tsunami survivors in Thailand. *Clinical Infectious Diseases*, **41**, pp. 982–990, 2005.

[39] Kateruttanakul, P., Paovilai, W. & Kongsaengdao, S., Respiratory complication of tsunami victims in Phuket and Phang-Nga. *Journal of the Medical Association of Thailand*, **88(6)**, pp. 754–758, 2005.

[40] Andresen, D., Donaldson, A., Choo, L., Knox, A., Klaassen, M., Ursic, C., Vonthethoff, L., Krilis, S. & Konecny, P., Multifocal cutaneous mucormycosis complicating polymicrobial wound infections in a tsunami survivor from Sri Lanka. *Lancet*, **365**, pp. 876–878, 2005.

[41] Moszynski, P., Disease threatens millions in wake of tsunami. *British Medical Journal*, **330**, p. 59, 2005.

[42] Krishnamoorthy, K., Jambulingam, P., Natajaran, R., Shriram, A.N., Das, P.K. & Sehgal, S.C., Altered environment and risk of malaria outbreak in

South Andaman, Andaman & Nicobar islands, India affected as by tsunami. *Malaria Journal*, **4**, p. 32, 2005.

[43] Orellana, C., Tackling infectious disease in the tsunami's wake. *Lancet*, **5**, p. 73, 2005.

[44] Anonymous. WHO appeals for 60 million US dollars to prevent disease outbreaks in tsunami affected Southeast Asia. *Annals of Saudi Medicine*, **25(2)**, p. 178, 2005.

[45] Balaraman, K., Sabesan, S., Jambulingam, P., Gunasekaran, K. & Boopathi Doss, P.S., Risk of outbreak of vector borne diseases in the tsunami hit areas of southern India. *Lancet*, **5**, pp. 128–129, 2005.

[46] Gunasekaran, K., Jamulingam, P., Srinivasan, R., Sadanandane, C., Doss, P.B., Sabesan, S., Balaraman, K. & Das, P., Malaria receptivity in these tsunami hit coastal villages of southern India. *Lancet*, **5**, pp. 531–532, 2005.

[47] Nakamura, M., Tanaka, F., Nakajima, S., Honma, M., Sakai, T., Kawakami, M., Endo, H., Onodera, M., Niiyama, M., Komatsu, T., Sakamaki, K., Onoda, T., Sakata, K., Morino, Y., Takahashi, T. & Makita, S., Comparison of the incidence of acute decompensated heart failure before and after the major tsunami in northeast Japan. *American Journal of Cardiology*, **110(12)**, pp. 1856–1860, 2012.

[48] Kishimoto, M. & Noda, M., The Great East Japan Earthquake: experiences and suggestions for survivors with diabetes (perspective). *PLoS Currents*, **4**: e4facf9d99b997, 2012. doi: 10.1371/4facf9d99b997.

[49] Nishizawa, M., Hoshide, S., Shimpo, M. & Kario, K., Disaster hypertension: experience from the great East Japan earthquake of 2011. *Current Hypertension Reports*, **14(5)**, pp. 375–381, 2012.

[50] Ueda, S., Hanzawa, K., Shibata, M. & Suzuki, S., High prevalence of deep vein thrombosis in tsunami-flooded shelters established after the great East-Japan earthquake. *Tohoku Journal of Experimental Medicine*, **227(3)**, pp. 199–202, 2012.

[51] Kanno, T., Iijima, K., Abe, Y., Koike, T., Shimada, N., Hoshi, T., Sano, N., Ohyauchi, M., Ito, H., Atsumi, T., Konishi, H., Asonuma, S. & Shimosegawa, T., Peptic ulcers after the Great East Japan earthquake and tsunami: possible existence of psychosocial stress ulcers in humans. *Journal of Gastroenterology*. 2012 Oct 3. [Epub ahead of print].

[52] WHO. *Psychosocial Consequences of Disasters: Prevention and Management*. WHO/MNH/PSF/91.3. 1992. World Health Organization: Geneva, Switzerland.

[53] Norris, F., Friedman, M., Watson, P., Byrne, C., Diaz, E. & Kaniasty, K., 60,000 disaster victims speak: Part I. An empirical review of the empirical literature, 1981-2001. *Psychiatry*, **65**, pp. 207–239, 2002.

[54] van Griensven, F., Chakkraband, M.L., Thienkrua, W., Pengjuntr, W., Lopes Cardozo, B., Tantipiwatanaskul, P., Mock, P.A., Ekassawin, S., Varangrat, A., Gotway, C., Sabin, M. & Tappero, J.W.; Thailand Post-Tsunami Mental Health Study Group, Mental health problems among adults in tsunami affected areas in southern Thailand. *JAMA*, **296**, pp. 537–548, 2006.

[55] Thienkrua, W., Lopes-Cardozo, B. & Chakkraban, M., Symptoms of post-dramatic stress disorder and depression among children in tsunami affected areas in southern Thailand. *JAMA*, **296**, pp. 549–559, 2006.
[56] Schultz, J., Russell, J. & Espinel, Z., Epidemiology of tropical cyclones. *Epidemiologic Reviews*, **27**, pp. 21–35, 2005.
[57] Kotozaki, Y. & Kawashima, R. Effects of the Higashi-Nihon earthquake: posttraumatic stress, psychological changes, and cortisol levels of survivors. *PLoS One*, **7(4)**, e34612, 2012.
[58] Rubin, G.J., Amlôt, R., Wessely, S. & Greenberg, N., Anxiety, distress and anger among British nationals in Japan following the Fukushima nuclear accident. *British Journal of Psychiatry*, **201**, pp. 400–407, 2012.
[59] Wilson, T., Chang, A. & Berro, A. US Screening of International Travelers for Radioactive Contamination After the Japanese Nuclear Plant Disaster in March 2011. *Disaster Medicine and Public Health Preparedness*, **6(3)**, pp. 291–296, 2012.