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Review Article

Tsunami risk reduction – are we better prepared today than in 2004?

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ABSTRACT

With over 220,000 fatalities, the 26 December 2004 Indian Ocean tsunami was one of the deadliest natural hazard events ever, and represents a landmark in disaster risk reduction governance in several ways. The 2004 Indian Ocean tsunami led to a better understanding of the likelihood of tsunami occurrence and potential tsunami inundation. For example, the Hyogo Framework Agreement was a direct result of this event. Since December 2004, Indonesia, Samoa, Chile and Japan were hit by altogether six destructive tsunamis in 2006, 2007, 2009, 2010 and 2011.

This article looks into the progress (or lack thereof) made in tsunami risk reduction at the local level during the past ten years, with focus on the densely populated coastal regions of Indonesia and Sri Lanka. The experience from other countries, as well as the progress made in the state of the art for assessment of tsunami hazard, vulnerability, exposure and risk are also summarized. In addition, extensive new warning systems enabling a rapid assessment of the potential coastal impact of a tsunami have been developed and implemented. However, the experience from the tsunami events in October 2010 in Indonesia and March 2011 in Japan clearly demonstrated that the tsunami risk mitigation measures implemented to date are far from adequate. The article also examines the progress in assessing and factoring in vulnerability aspects in tsunami risk reduction, highlighted through two case studies in Padang (Indonesia) and Galle (Sri Lanka). In this regard, societal awareness and behavioural response to tsunamis are addressed. Recommendations about how the improved knowledge about tsunami hazard, vulnerability and exposure assessment gained over the past decade could be better implemented into tsunami risk reduction measures are provided at the end of the article.

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1. Introduction

Recent disasters triggered by natural hazards provide further evidence of the need for disaster risk reduction (DRR) strategies that address the mitigation of hazard impact and reduction of vulnerability and its root causes. This need is also stressed by the post-2015 Hyogo Framework for Action (HFA) process. In this context, tsunamis have played an important role due to their devastating impacts, exemplifying the tremendous number of fatalities and losses that could have been reduced by effective risk reduction activities. With over 220,000 fatalities, the 26 December 2004 Indian Ocean tsunami was one of the deadliest disasters triggered by a natural hazard event ([67]). It demonstrated the need for more research, improved planning activities, awareness raising, as well as the need for establishing early warning systems [105]. The Indian Ocean tsunami provided important lessons for developing the HFA and sharpened the commitment for its implementation [103,106]. Although a variety of tsunami risk reduction measures such as the ongoing establishment of the Indian Ocean tsunami early warning system have been implemented since December 2004, the tsunamis that occurred during the last decade illustrated remaining deficiencies. The 11th March 2011 Tohoku Earthquake and subsequent tsunami, which caused a nuclear catastrophe, is just the most recent example (Table 1). The tsunami hitting the Mentawai Islands in Indonesia on 24 th October 2010 is another. Both events occurred in regions were tsunami risk prevention measures had been implemented.

In hindsight, the 2004 Indian Ocean tsunami should not have come as a surprise [82]. Old historical events occurring two centuries ago provided a warning sign that was raised a short time before the disaster hit [18]. Recent paleotsunami deposits have revealed evidence for past events in pre-historical times [44], meaning that the 2004 Indian Ocean tsunami is not an isolated event. The 2004 Indian Ocean tsunami did introduce a paradigm change in the sense that previous models for constraining earthquake magnitudes along fault zones are now refuted [90]. As a consequence, megathrust earthquakes emerging from any of the large subduction zones in the world should not be ruled out.

The tsunamis that hit Japan in 2011 and Mentawai Islands in 2010 [34] have revealed weaknesses in the way society deals with tsunami hazard information. At that time, a new warning system was at place in Indonesia, but there were no tsunami sirens located along the most exposed shorelines near the Sumatra trench. Here, the population did not self-evacuate, maybe because of many false warnings and earlier tremors, and perhaps also due to the lack of proper systems for conveying the warnings [94]. A similar lack of awareness was demonstrated in by the Samoa tsunami in 2009, where many people drowned in their cars when they could have evacuated by foot [94]. The 2011 Tohoku tsunami was more severe than the tsunami barriers were designed for [20]. According to Ogasawara et al. [74], 25 of 55 tsunami barriers in Iwate prefecture were damaged and also almost half of the disaster prevention infrastructure has been destroyed. Even the breakwater installed in Kamaishi, being the deepest breakwater in the world (1950 m long and 63 m deep), was heavily damaged. Although seawalls were partly overtopped and dikes were heavily damaged, these structures reduced the wave height and avoided a greater damage [29,84]. The Japanese tsunami hazard maps were largely based on historical earthquake records limiting the earthquake moment magnitude to about 8, one order of magnitude lower than the 2011 event [37]. Recent analyses have in fact shown that a tsunami of this size may have a return period of about 500 years and should by no means have been a surprise [46]. A 500-year return period is well below the typical return periods of the extreme events nuclear power plants are designed to withstand. Still, one should keep in mind that the Japan, like Indonesia and Sri Lanka, faced run-up exceeding 10 m over large areas, with horizontal inundation extending one or sometimes several kilometres, leaving many cities almost totally destroyed. The fact that the relative death toll in Japan was one order of magnitude lower than that caused by the Indian Ocean tsunami is one of the strongest indicators that the exposed