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Introduction

1 The earthquake rating 9.3 on the Richter scale that occurred in the Indian Ocean on December 26th 2004 was the second most violent earthquake recorded since 1900 (Stein & Okal, 2005; Munich Re, 2005). Along a fault line of around 1200 km, the tectonic plates collided and the Indian plate was forced under by the Burma plate, which rose by ten metres on average, forming a subduction zone (Ni *et al*, 2005). It was this tectonic movement that caused the tsunami, which in a few hours caused nearly 226 000 deaths, the equivalent of all the natural disasters of the previous ten years, and the displacement of more than one and a half million people living on the coastlines of twelve countries and two continents (Table 1).

Table 1: Countries affected by the tsunami, number of dead, missing, total[1] and displaced persons (statistics for 6th May 2005)

Continent/Country	Number of dead	Number missing	Total	Number of displaced persons
Asia				
Indonesia	128645	37063	165708	532898
Sri Lanka	31147	4115	35262	519063
India	10749	5640	16389	638297
Thailand	5395	2845	8240	NA
Maldives	82	26	108	11568
Malaysia	68	6	74	8000
Burma	61	0	61	2592
Bangladesh	2	0	2	0
Africa				
Somalia	150	NA	298	5000
Tanzania	10	NA	10	NA
Seychelles	3	NA	3	40
Kenya	1	NA	1	NA
Total	176313	49695	226008	1717458

(Sources: USAID, 2005; AFP, 2005)

2 One terrible aspect of this disaster was its suddenness. Most of the people close to the beaches and shorelines who were unable to retreat quickly to higher ground were drowned, as for example in the province of Aceh in the extreme north of the Sumatra. On January 14th 2005, more than 110 000 dead were reported, compared to just 1400 people hospitalised for minor injuries – fractures, open wounds for the most part (Pincock, 2005). The non-serious nature of injuries was confirmed in Thailand, where only 0.3% of the injured sent to hospital failed to survive (Watts, 2005). The situation was similar in India, where, three weeks after the disaster, very few of the 30 000 injured in the tsunami were still hospitalised (Chatterjee, 2005). Again in the area of health, the widely dreaded epidemics much discussed after this natural disaster (Brauman, 2005; Van Rooyen & Leaning, 2005) did not develop (WHO, 2005). However what unanimously mobilised the medical community was the impact of psychological trauma, difficult to quantify, on the local populations, following the cataclysm (Silove & Zwi, 2005), so that psychological follow-up was thought to be necessary over several years (Hampton, 2005).

3 The disaster had unprecedented impact on the levels of Western public generosity. NGOs collected more money between Christmas and the New Year than over the whole of the

previous year (Debarbieux, 2005). The role of the media, which, as for the September 11th attack, fed public the public ever-hungry for morbid images with continuously looping coverage of the catastrophic scenes, certainly has something to do with the emotional impact and the popular mobilisation (de Longueville & Ozer, 2005). As an example, the special televised news broadcast on December 27th devoted to the tsunami, and mainly targeting Western victims, was the most watched broadcast of the year 2004 in French-speaking Belgium, with more than 900 000 viewers.

4 The humanitarian mobilisation that followed was also impressive. Thus on February 14th 2005 as many as 97 NGOs, 42 governmental organisations and 25 international organisations were present in the island of Sumatra alone (Reliefweb, 2005) – unprecedented in the history of humanitarian aid. For these various reasons, numerous observers went as far as to describe this cataclysm as the first globalised natural disaster (Anonyme, 2005a; Debarbieux, 2005). By way of the analysis of this natural disaster, this paper sets out to explore the challenges of the management of tsunami-related risks. Firstly we will return to one major controversy concerning this natural disaster, which was the absence of a tsunami warning system in the Indian Ocean. Secondly, options for prospective management of this risk (territorial planning, education) will be explored, because the implementation of a warning system is only one component in risk reduction strategies (Bird & Lubkowski, 2005; Pons, 2005a).

The absence of a tsunami warning system in the Indian Ocean

5 The idea of the need for a tsunami warning system fuelled wide debate in the aftermath of the disaster in the Indian Ocean. The controversy concerning responsibilities in this disaster were perfectly foreseeable, as after most natural events. Thus after the storm of the century, named "Lothar", which devastated vast regions across Europe at the end of 1999 (Bresch *el al*, 2000), all eyes and all criticism focused on Météo-France, the meteorological office, who had not broadcast a warning bulletin for this unprecedented disaster. In December 2003 after the earthquake in Bam, all fingers were pointing towards the Iranian authorities for having failed to invest in anti-seismic building technologies, and in the establishment of emergency plans (Munich Re, 2004). In the case of the Indian Ocean tsunami, many of the observers and specialists expressed indignation at the absence of a warning system (Marris, 2005).

6 This point has nevertheless been one of the main subjects of controversy in connection with this disaster. Indeed, a survey carried out in the immediate aftermath among 500 civil engineers specialised in geo-risk shows that an appreciable proportion of the respondents (34%) considered that it was not relevant to invest in a tsunami warning system in the Indian Ocean (Parker, 2005).

7 There are different reasons for this uncertainty as to the efficacy of a warning system in South-East Asia, and more particularly the Indian Ocean.

8 The first relates to the rarity of events of this type on the coasts around the Indian Ocean. Indeed, with the exception of countries with shores on the Pacific, the natural risk associated with tsunamis has been little studied because of their very infrequent occurrence in the course of recent centuries. This also explains why the latest world map of natural risks merely outlines the coasts historically affected by tsunamis, without the systematic analysis of the risk that is performed for other types of natural disasters (Berz *et al*, 2001). Further to this, a recent analysis of the tsunami risk worldwide estimated that the period for the return of a wave 10 metres high, that is to say on a scale similar to, or rather smaller, than the one that occurred on December 26th 2004, was of the order of 1000 years for the Indian Ocean, just as it is thought to be for the North Atlantic (Schiermeler, 2005b). Other sources (Carré, 2005) show that in the long term it is the Pacific Ocean that has seen 75% of the tsunamis recorded, well ahead of the Mediterranean (12%), the Atlantic (9%) and the Indian Ocean (3%). In fact none of the shores devastated in the recent tsunami was confronted with the risk over the last 120 years (Figure 1, Brauner *et al*, 2005). It is true that the tsunami caused by the eruption of Krakatoa in 1883 was registered on the coasts of Sri Lanka and India, but the wave was never higher than one metre (Choi *et al*, 2003), compared to the waves of 5 to 12 metres in December 2004 (Chadha *et al*,

2005; Liu *et al*, 205, Yalciner *et al*, 2005). It should be recalled here that the remembrances of disasters are the main instrument for foreseeing and guarding against natural risks (d'Ercole & Dollfus, 1996). In addition to this, the few recent tsunamis that affected Indonesia (Flores in 1992, western Java in 1994, and Biak in 1996) claiming some 2700 victims only concerned the eastern part of the country. This very low probability of occurrence of tsunamis in the Indian Ocean explains why in June 2004 the coastal nations refused the Japanese offer to establish a tsunami warning system in the region (Parker, 2005). If solely the period of probable return of this type of risk is considered, it seems unjustified to criticise the political decision-makers in these recently devastated countries.

9 The generally small numbers of victims in tsunamis is probably another reason that influenced the under-estimation of the risk. Thus from 1900 to 2003 only 8 tsunamis caused the death of more than 1000 people, and none caused more than 5000 deaths (Table 2). Compared to other types of natural disasters (earthquakes, floods, hurricanes) occurring yearly across Asia, these figures are small.

10 The ten largest disasters related to tsunamis since the start of the 20th century yield a total of less than 20 000 dead. These figures also cast light on the very exceptional nature of the disaster of December 26th 2004.

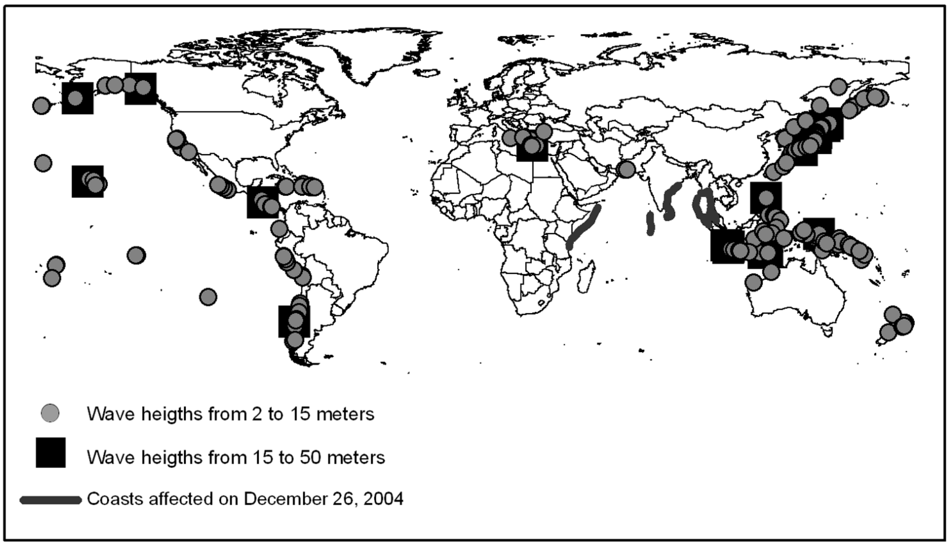
Table 2: The ten most deadly tsunamis since 1900

Date	Main regions affected	Deaths
26/12/2004	Indonesia (Sumatra), Sri Lanka, India, Thailand, Maldives, Somalia, etc.	>226000
17/08/1976	Philippines	4000
02/03/1933	Japan (Sanriku)	3060
21/05/1960	Chile, USA (Hawaii), Japan	3000
12/12/1992	Indonesia (Flores)	2500
17/07/1998	Papua New Guinea	2400
20/12/1946	Japan (Nankaido)	2000
05/11/1952	Russia (Paramushir island, Kamchatka)	1300
07/12/1944	Japan (Honshu)	1000
31/01/1906	Ecuador, Colombia	500

(Source: Munich Re, 2005)

11 The third reason suggested by certain specialists is that the devastated Indonesian coastlines were extremely close to the fault that caused the tsunami (about 200 km). Therefore 43 minutes after the earthquake (Boen, 2005) the wave had already hit Sumatra, with heights ranging from 4 metres in Meulaboh to nearly 35 metres in Lhok Nga (Boen, 2005; Tsuji et al, 2005; USGS, 2005b). The town of Banda Aceh found itself under 5 to 12 metres of water (Borrero, 2005; USGS, 2005a; USGS, 2005b). According to several experts, this would not have allowed sufficient time for a detailed analysis of all the information required to issue a reliable forecast of the scale of the tsunami, identifying the zones threatened, and then to launch the alert (Munich Re, 2005b; Parker, 2005).

Figure 1: Geographical distribution of wave heights for tsunamis from 1883 to 2003, and shorelines probably hit by wave heights of over 2 metres in the tsunami of December 26th 2004



(After Brauner *et al*, 2005 and Schiermeler, 2005a)

12 As a comparison, after the Lisbon earthquake in 1755 which caused the greatest seismic disaster ever recorded in Western Europe (100 000 dead) the tsunami took 16 to 30 minutes to sweep across the coast of the Algarve, 30 minutes to reach Lisbon, and 26 to 34 minutes to devastate the town of Safi in Morocco (Chester, 2001). If a tsunami similar to the Asian "big one" had occurred earlier in Europe, what would have been the consequences in countries, where the very word tsunami was unfamiliar to the general public? This being said, it is probable that thousands of lives could have been saved in India and Sri Lanka if the transfer of information and warnings had been operational (see Table 3 below).

13 The last reason generally given is the irrelevance of the establishment of an early warning system that can be efficient in societies possessing optimally functioning information networks (such as the USA and Japan), in view of the reality of daily life in several of the countries hit by the disaster in the Indian Ocean (Bird & Lubkowski, 2005; Ozer, 2005). To illustrate this, a chronology positioning the salient events observed in the first hours after the seismic tremor is presented in Table 3. If we look at this chain of events, the most striking aspect is the slow rate at which information relating to the tsunami risk reached key individuals who might have taken concrete action in the field. Thus the Pacific Tsunami Warning Center (PTWC) tried in vain to contact their Indonesian colleagues in Jakarta, at a time when the wave had already ebbed from Sumatra. And anyhow, would things have been very different if a scientist in Jakarta had been warned, even in good time? How would the information have reached Banda Aceh? And once it got there, how could the information have been issued massively to the population of the main town, and to the villages along the coast, often without telephones?

14 Following this disaster, there was to be not one tsunami warning system in the Indian Ocean, but four....Thus India allocated funding of 29.10^6 US$ for the protection of its coastline. Germany envisaged devoting 40.10^6 US$ to establishing a tsunami warning system for the Indonesian shorelines, while Thailand planned its own coastal protection. The United Nations for their part were to allocate 40.10^6 US$ for a system covering the Indian Ocean, to be operational from June 2006. They also undertook to establish a global warning system by June 2007 (AFP, 2005a; Cyranoski, 2005; Jayaraman, 2005). It goes without saying that if efforts are not coordinated, and without a pooling of all the data required for a reliable diagnosis of the situation (Anonyme, 2005c; Cyranoski, 2005) the confusion could be enormous. In addition, it can also be wondered what system could be established in the space of a few months, when the USA and Japan have taken more than 20 years to develop and validate digital models for the prediction of the trajectories of tsunamis in the Pacific Ocean, essential for a reliable warning system (Synolakis, 2005).

Table 3: Chronology of events following the quake under the floor of the Indian Ocean

Chronology	Events reported
00:59 GMT	An earthquake of magnitude 9.0 on the Richter scale occurs in the sea west of the island of Sumatra causing the tsunami
Earthquake + 00h08'	Seismic signals from the earthquake recorded in Australia reach the (Pacific Tsunami Warning Center (PTWC) in Hawaii. The alarm is raised.
Earthquake + 00h15'	PTWC issues a bulletin indicating that an earthquake of magnitude 8.0 on the Richter scale has occurred, without risk for the Pacific nations. The USGS (United States Geological Survey) circulates the information internally
Earthquake + 00h25'	USGS revises the magnitude to 8.2
Earthquake + 00h30'	The tsunami hits the west of the island of Sumatra
Earthquake + 00h43'	The tsunami hits the town of Banda Aceh
Earthquake + 01h00'	The PTWC issues a second bulletin revising the magnitude of the earthquake to 8.5 and identifies the possibility of a local tsunami close to the epicentre. PTWC attempts to warn colleagues in Indonesia, without succeeding. Australia is alerted
Earthquake + 01h10'	The tsunami hits Thailand
Earthquake + 01h30'	The Indonesian authorities in Jakarta finally receive the second PTWC bulletin
Earthquake + 02h00'	The tsunami hits the east of Sri Lanka
Earthquake + 02h15'	The tsunami reaches India
Earthquake + 02h25'	The Indian meteorological office faxes warning bulletin to the science and technology Ministry. But it is a wrong number
Earthquake + 02h30'	The first information relating to the tsunami and its victims appears on Internet
Earthquake + 02h45'	The Indian Meteorological Office faxes a warning bulletin to the Ministry of the Interior. The message is received.
Earthquake + 03h00'	The United States ambassador in Sri Lanka takes the initiative of establishing permanent contact with PTWC so as to be able to warn the local authorities directly in case of secondary quakes
Earthquake + 03h30'	The tsunami reaches the Maldives
Earthquake + 03h45'	Bangkok issues a bulletin for fishermen warning of the possibility of waves of 5 metres
Earthquake + 04h00'	Members of the Federal Government in New Delhi are informed of the disaster
Earthquake + 04h25'	The Seismic Department in Harvard University revises the magnitude of the earthquake to 8.9
Earthquake + 07h15'	The PTWC informs the American State Department of the potential threat of a tsunami in Africa and Madagascar. At the same moment the tsunami reaches Somalia.
Earthquake + 14h30'	The PTWC warns that the waves are likely to reach the Pacific countries. In the hours following, waves reach a height of 50cm in places in Chile and on the coasts of North America
Earthquake + 3 months	The journal Nature publishes the results of Stein & Okal (2005) who revise the magnitude of the earthquake to 9.3

(after Boen, 2005; Delbecq *et al.*, 2005; Marris, 2005; Orfanogiannaki *et al.*, 2005; Schiermeler, 2005a; Stein & Okal, 2005)

Territorial development integrating the tsunami risk

15 In all events, the existence of a tsunami warning system can hardly be more than a means to restrict losses (Kempf, 2005a). It needs to be accompanied by measures for appropriate coastal management in the risk-prone areas. Thus the American National Tsunami Hazard Migration Program recommends seven measures to reduce the effects of tsunamis on property and persons (NTHMP, 2001):

- Knowing a community's tsunami risk: hazard, vulnerability and exposure. The city of Heraklion (Crete) has thus developed a very detailed plan not only of exposed zones, but also of the most vulnerable spots. To do this, the study integrated numerous factors relating to the structure of the habitat and the physical environment into a GIS, and also gathered socio-economic data (Papathoma et al, 2003).
- Avoiding new development in tsunami run-up areas to minimise future tsunami losses.
- Opting for specific developments in zones exposed to tsunamis by work on specific sites (for instance, raising levels)
- Applying specific building standards to new buildings (resistance to wave impact, consolidation of foundations etc) so as to minimise damage by tsunamis. In Banda Aceh, the work by Boen (2005) did indeed show that the buildings constructed according to anti-seismic specifications resisted the tsunami, while the others were shattered by the wave.
- Protecting existing buildings and infrastructures in the exposed zones by anti-tsunami embankments or walls, which, although costly and not attractive to the eye, have proved efficient, in particular in certain exposed bays in Japan (Pons, 2005a, 2005b).
- Taking specific precautions when establishing infrastructures that are needed during crises (hospitals, fire stations, civilian protection etc).
- Drawing up evacuation plans. Here there are two possible solutions: firstly "horizontal" evacuation, consisting in withdrawal inland towards high ground, and secondly "vertical" evacuation, consisting in finding refuge in the upper storeys of buildings. This second solution is recommended when the time for horizontal evacuation is very short, when the population density is very high, and when the means for horizontal evacuation ((roads, bridges etc) are few, or in the case of islands with few relief features (e.g. the Maldives). In zones where buildings are not very high, the construction of high platforms in coastal villages can be envisaged. This was indeed the chosen option in the last decade in the Ganges delta in Bangladesh (Kempf, 2005b), an area chronically affected by flooding and tropical cyclones causing temporary rises in water levels.

16 It can be wondered if measures of this type are a judicious use of financial resources. Indeed, while it is probable that the construction of more robust buildings is not economically viable to guard against exceptional events such as a major tsunami occurring only every 1000 years, it is nevertheless important to underline that measures of this sort would also substantially reduce losses in case of earthquakes and storms, which are for their part frequent events in the region.

17 To a certain extent, it would appear that the authorities in the countries affected have partly taken in the lessons of the tsunami. Sri Lanka, for instance, has declared that it is now forbidden to build less than 300 metres from the coast, while in India, the no-build zone is no longer applied to the first 500 metres, but to the first kilometre (Anonyme, 2005b). In Aceh province, Sumatra, the authorities have gone even further. All the coastal towns are to be moved inland and protected from the sea by a buffer zone of two kilometres. Inside this buffer zone, it is to be forbidden to build houses, office buildings, markets or shopping precincts. The buffer zone is to be divided into three parts. The first, 300 metres deep and protected from the sea by a dyke, will comprise mangroves, palms and pines. The second, measuring 1600 metres is to be exclusive to fishermen, and the last strip 100 deep will be planted with trees (Sukarsono, 2005).

18 These decisions can only be welcomed, but it seems important to temper enthusiasm. Globally, it does seem difficult to enforce regulations of this sort in countries in the South where fishing is one of the resources enabling populations to survive in the coastal areas. In addition, "spontaneous" settlement is widespread, especially in zones suffering internal armed conflict,

as in northern Sumatra (Fau, 2005). It therefore seems complicated to enforce the strict application of certain measures of territorial development. And this is all the more so as the memory of the disaster fades, becomes deformed, and progressively disappears (d'Ercole & Dollfus, 1996), making it less and less likely that regulations will be observed. Another important aspect is that the decision to outline a buffer zone of two kilometres applies only to Aceh province. This all too well illustrates the fact that decisions are reached to reduce risk only after an actual disaster, which shows a lack of political perspicacity and/or determination, and a lack of understanding of the risk. We will thus have to wait for another Indonesian island to undergo a coastal disaster for it to use the example of Aceh province to redevelop (assuming the Aceh model is a success).

The education of the population in the risk culture

19 There is a general consensus regarding the need to establish educational programmes targeting the general population so as to instil a certain risk culture and to ensure that prevention reflexes are well established (Delbecq, 2004; United Nations, 2004). This should mainly target the education of children, who are very vulnerable to this risk, starting in primary school, in particular using strip cartoons (ITIC, undated); periodic evacuation exercises should also be implemented. In this way, the next time the coastal populations feel an earthquake and see the sea receding abnormally for a few minutes, they will know it is time to take refuge inland or on high ground. It takes only a short time to register this simple notion, but it can save lives. A study conducted among Western tourists who witnessed the disaster on the islands of Phuket and Phi Phi in Thailand are a good illustration. It reports that a seismic tremor was felt slightly, and that one hour later the sea receded by 200 to 300 metres for 2 to 5 minutes before a tsunami of 10 metres swept 400 metres inland (Orfanogiannaki *et al*, 2005). The time available to these tourists to cover so short a distance inland was in fact ample to save all the lives that were lost, if the prevention reflex had been present.

20 On the coasts of Japan, Hawaii or certain coastlines of the USA every person knows what to do in case of tsunami alert. Even if no warning is issued, but the person feels a tremor, he or she will know how to act. Thus Sugimoto and colleagues (2003) showed that in case of an earthquake in the close vicinity, losses in human lives could be reduced by 10 or 15% if the populations started evacuation 15 minutes before the arrival of the tsunami. Losses would be virtually nil if the wave arrived 30 minutes after the quake. If the 165 000 dead in Sumatra are compared with these expected results when the notion of the tsunami risk has been fully integrated, it is clear that training and education are priceless.

21 Officers also need to be trained in the efficient diffusion of the information they possess and warnings received. For this purpose, a coordination centre able to contact the right people at any time should be established. In the USA, there is specific training for such officers (Beaulieu, 2001). It covers all the procedures to adopt for warnings to be issued in the most efficient manner.

Conclusion

22 Overall, it can be feared that the natural hazards threatening coastlines will increasingly become disasters of great magnitude, because vulnerability along coasts has increased markedly in recent decades, following the massive settlement of populations close to the sea, mainly for economic reasons. Desperately seeking new space along the coasts, these new arrivals settle regardless of the ecosystems which are in themselves buffer zones acting as very efficient brakes on tsunamis, and also on cyclones, which are events that are far more frequent in the region (Dahdouh-Guebas *et al*, 2005).

23 The analysis of the tsunami of December 26th 2004 highlights a string of malfunctioning in the management of the disaster in the first hours after the earthquake. The historical study of tsunamis in the Indian Ocean explains why there was no early warning system in South-East Asia. It has also been shown that this type of system alone could not have saved the 165 000 victims in Indonesia. However, the application of well thought-out measures of territorial development integrating the tsunami risk, and the development of a certain risk

culture in the populations by way of educational programmes, could have considerably reduced vulnerability.

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Notes

1 Five months after the disaster, the different countries considered the missing persons dead.

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Abstract

The tsunami that affected the coasts of the Indian ocean on December 26, 2004 claimed close to 226 000 lives, mainly on the island of Sumatra, Indonesia, which suffered overwhelming devastation. This article asks whether a tsunami warning system is needed in the Indian Ocean, where the probability of experiencing a similar catastrophe is very small. In addition, other alternatives, including land use planning and education focused on tsunami risk management, are presented. Their application could considerably reduce financial and human losses if a disaster of this nature was to occur again.
Keywords : education, hazard, tsunami, natural risk, vulnerability, risk management, warning system, land use planning, south-east Asia