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EDITORIAL

Preventive disaster management of extreme natural events

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Abstract Several recent extreme natural events resulted in great humanitarian tragedies because of weak preventive disaster management. Here we analyze several factors (natural, economical, political, awareness, and preparedness) that brought about the humanitarian tragedies of the early 21st century. We discuss then the role of science in the preventive disaster management of extreme natural events.

Keywords Extreme event · Geohazard · Risk · Society · Disaster management · Preparedness

1 Introduction

Extreme natural events struck the Earth and our society in recent times, among them: the October 2004 large Niigata earthquake (magnitude $M = 6.6$ on the Richter scale) in Japan and the December 2004 great Aceh-Sumatra ($M = 9.0$) earthquake and devastating tsunami in the Indian Ocean, the violent hurricanes August 2004

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Charley (category 4 on the Saffir-Simpson scale), September 2004 Ivan (category 3), August 2005 Katrina (category 4 at landfall), and September 2005 Rita (category 3 at landfall) in the Gulf Coast, and the October 2005 large earthquake in Pakistan ($M = 7.6$). Such natural events are rare, but not unexpected. The earthquake and tsunami in the Indian Ocean (about 300,000 people killed and more than 1 million displaced in ten countries in South Asia and East Africa), hurricane Katrina (over a thousand fatalities, hundred thousands were displaced from New Orleans and surroundings, and hundred billions of dollars of economical damage; see http://www.newscientist.com/channel/earth/hurricane), and earthquake in Pakistan (at least 86,000 people killed, more than 69,000 injured and extensive damage in Northern Pakistan) resulted in large humanitarian disasters because of weak preventive disaster management. Fortunately, the Niigata earthquake, and hurricanes Ivan, Charley, and Rita did not lead to extreme human losses, but became the costliest natural disasters of the 21st century. The Niigata earthquake generated economic losses of US$ 28 billions; and the losses due to the hurricanes Ivan and Charley are estimated to be US$ 23 and 18 billions respectively (Munich Re 2005).

Scientists knew about historical devastating earthquakes and tsunamis, which occurred in the Indian Ocean region or earthquakes in Himalayas and Japanese islands. Scientists and engineers warned for years that the levees, preventing the below-sea-level city of New Orleans from flooding, were built to withstand only category 3 hurricanes. And officials have warned for years that a category 4 could cause the levees to fail. ‘‘Eventually a major hurricane will hit New Orleans head on, instead of being just a close call. It’s happened before and it’ll happen again’’ (http://www.nola.com/hurricane).

Therefore, it is a matter of *when* the rare extreme natural event occurs, not *if*. Time is an important parameter in natural disaster management, especially when it concerns extreme events. An extreme event, in general, cannot be predicted in full details. So far, geophysics can put confidence limits of uncertainty, although limits are very wide, on the time, place and magnitude of an anticipated extreme event (e.g., earthquake, tsunami, flood, and cyclone), which give insufficient information for disaster management. Nevertheless hazard preparedness is vital for society. The less often natural events occur (and the large extreme events are rare by definition), the more often the disaster managers postpone the preparedness for the events. The tendency to reduce the funding for preventive disaster management of natural catastrophes rarely follows the rules of responsible stewardship for future generations, neither in developing countries nor in highly developed economies.

An implementation of preventive measures to mitigate the aftermaths of rare extreme events in day-to-day activity of disaster management institutions (and other state institutions responsible for disaster mitigation) is a challenging problem. Despite the measures drawn by scientists and engineers being based on deep knowledge, forecasts and modeling of rare natural events, the measures are estimated by governmental financial structures through a cost-benefit ratio. This ratio tells us what would be the benefit for society if money were spent to implement a particular large and costly project. In general, the ratio is a useful tool in project evaluation, but it should be used efficiently. Values of human lives, psychological hardness, societal unrest, and other non-economic goods are extremely difficult to evaluate. As a result, in many cases the cost-benefit ratio evaluators favor the projects with a short-term tangible benefit for society (and politicians would be happy to see results of funded projects during their term of office), but the mitigation of rare natural events cannot be evaluated only by the short-term tangible benefit.

In this paper we analyze how and why the recent natural disasters turned into humanitarian tragedies and discuss the role of science in the preventive disaster management of extreme natural events.

2 From natural extreme event to humanitarian disaster

There is an increasing trend worldwide in the number of large disasters and their total economic impacts (see Table 1). Among the reasons for such an increase, we can mention a rise of population, better standard of living, and concentration of population in hazard-prone regions (especially in coastal and hill-slope regions). If the United States is considered, natural hazards losses from 1960–2003 are increasing; weather-related events produce more dollar damages than any other hazards; and flooding (21%), hurricanes (19%), and earthquakes (17%) cause over half of the total estimated damage (Cutter and Emrich 2005).

We consider several factors that brought about the humanitarian tragedies of the early 21st century. We divide them in natural, economic, and political factors, factors of awareness and preparedness.

2.1 Natural factor

The devastating 2004 Aceh-Sumatra mega-thrust earthquake occurred at the interface of the India and Burma plates and was caused by the release of huge tectonic stresses that accumulate as the India plate subducts beneath the overriding Burma plate. The earthquake was the fourth largest earthquake in the world since 1900 and the largest since the 1964 Prince William Sound, Alaska earthquake. Between 1900 and 25th December 2004, the largest earthquake along the subduction zone from southern Sumatra to the Andaman Islands occurred in 2000 and had a magnitude of 7.9. A magnitude 8.4 earthquake occurred in 1797, a magnitude 8.5 in 1861, and a magnitude 8.7 in 1833 and were all followed by powerful tsunamis (300, several thousand, and 36,000 fatalities, respectively) (see http://www.gps.caltech.edu/~sieh/publications/a10.html and http://www.tsun.sscc.ru/tsulab/20041226tsun.htm).

Flooding (including storm surge and cyclone induced) is the single most destructive type of natural disaster that strikes humans and their livelihoods around the world. In the last few years, catastrophic flooding was experienced in Asia (e.g., China, Bangladesh, India), Europe (e.g., Germany, Poland), the USA, and elsewhere. Flooding is not restricted to the least developed nations, but also occurs in devastating fashion in the most developed and industrialized countries of the world. Flooding in Europe in 2002 caused aggregate economical losses of more than 16 billion US dollars (Munich Re 2005). However, it is the people of the least developed nations that suffer the highest toll from the occurrence of flooding. When

Table 1 A comparison of aggregate loss figures for the recent decades. Losses in US$$10^9$, in 2004 values (Munich Re 2005)

Decade	1950–1959	1960–1969	1970–1979	1980–1989	1990–1999	Last 10 years
Number of events	20	27	47	63	91	63
Economic losses	44.9	80.5	147.6	228.0	703.6	566.8

natural disasters such as flooding occur in developing nations, they can effectively wipe out decades of investments in infrastructure and the personal wealth of many of its people, not to mention the countless loss of lives, physical injuries, and psychological traumata that result from the disasters.

Hurricanes Katrina and Rita were major class hurricanes (both Category 5 events weakened just before landfall), which seem to be more frequent under global warming. Katrina is announced to be the most devastating hurricane and costliest natural disaster in the USA history (Associated Press 2005). Rita was the seventeenth event in the 2005 Atlantic hurricane season. The season was the busiest on record and extends the active hurricane cycle that began in 1995. According to NOAA data (National Oceanic and Atmospheric Administration 2006), the 2005 hurricane season included 27 named storms (previous record: 21 in 1933), 15 hurricanes (12 in 1969), and 4 major hurricanes (Dennis, Katrina, Rita, and Wilma) hitting the U.S. (3, most recently in 2004). Possible reasons for the large number of events are rising sea surface temperature and increasing atmospheric water vapor that can potentially enhance tropical convection, including thunderstorms and the development of tropical storms (Trenberth 2005). The cyclone routes are also changing as experienced in Japan. In the period 1950–2003, the average annual number of tropical cyclones making landfall in Japan was 2.7. The largest annual number of landfalls was six since 1951. The year 2004 was a record year with a total of ten typhoons (Munich Re 2005).

2.2 Economic factor

The societal costs and benefits must be re-examined as well as the efforts to improve public safety. If about 5–10% of the funds, necessary for recovery and rehabilitation after a disaster, would be spent to mitigate an anticipated event, it could in effect save lives, constructions, and other resources. The decision on whether to adopt preventive mitigation measures to reduce losses from catastrophic natural disasters is based on the cost-benefit ratio. The decision may not be easily justified if a standard discount rate is applied. The discount rate is determined by the societal preference and the opportunity cost of investment in the market. It is decided by a number of factors and reflects the overall societal as well as economic reality. The rate for public investment is different from that of commercial goods, especially if it is concerned in the future generation. Let us consider a simple example.

Assume that a T-year extreme event can occur in a large city (e.g., New Orleans) and that the probability of occurrence of such an event and the resulting losses in a year are constant over time $1/T$. Assume that if a disaster occurs the city will be restored to its pre-disaster condition and be functional again as it was prior to the next disaster whenever it comes. The decision as to whether or not invest in a natural disaster mitigation measure is determined by comparing the cost of the preventive mitigation C_m with the expected benefits B_e, which can be assessed by the following formula

$$B_e \propto \sum_{t=1}^{N} (1/T)L/(1+r)^t.$$

Here $1/T$ is the annual probability of natural disaster occurrence causing damage without preventive mitigation measures against T-year or severer event, L is the average loss reduction from mitigation measures against T-year or severer event (e.g., $L = 20 \times 10^9$ in US$ for $T = 10$–100 year), r is the annual discount rate, and N is the time horizon to be considered for the assessment. Since natural phenomena are considered, the probability of occurrence of the T-year event does not change if the event occurs or does not occur or regardless whether preventive works are implemented or not. Preventive works, however, can reduce the amount of losses. The average reduction of losses by these preventive works is assumed to be L in the model estimations although the value depends on the magnitude (or return period) of extreme events actually occurred.

Table 2 presents the approximate expected benefits for various values of T, r, and N. Despite their simplicity, the estimations of the expected benefits can be accepted as a first approximation to real economical benefits of preventive mitigation measures. If the mitigation measure costs less than B_e, then it is cost-effective for the business to adopt it. The cost of Coast 2050 project to protect New Orleans against flooding was estimated to be US$14 billion (Fischetti 2001). The expected benefits, which we calculated over 100/10 years for the city, ranges from about US$4 to 16 billion for 100/10-year extreme event with the annual discount rate of 5%. The discount rate reduction results in the growth of the expected benefits, and this should be taken into account by the governments of natural hazard-prone areas.

The large and costly engineering plan Coast 2050 developed in 1998 (!) by scientists, engineers, metropolitan planners, and Louisiana officials might have helped to save New Orleans in 2005, but had gone unrealized, despite the fact that it went to the US Congress in proper time. Meanwhile the Congress preferred to allot $7 billion for the program to refresh the dying Florida everglades, but did not reach conclusions concerning funding of the Coast 2050 project (Fischetti 2005). There could exist many reasons why the Coast 2005 project was not funded, but one of the reasons is most likely to be a long-term and non-market benefit for society, even less visible than ecological restoration.

In Japan, high risk urban districts such as the eastern part of Tokyo and the central part of Osaka are, although only partially yet, protected by so called super-levees, the width being about 30 times of the height or, in practice, 100 to 300-m-wide breakage-free levees. It is indeed costly but is made economically feasible as combined with redevelopment of densely urbanized riparian zones by which the economic value of land increases and pays off (Kundzewicz and Takeuchi 1999).

Therefore, in democratic societies politicians together with scientists and engineers should inform the public on a variety of major (vital but costly) regional, national or international projects proposed and learn their opinion on the projects. Possible means to draw their opinion would include (i) Contingent Valuation method (Cummings et al. 1986) to quantify the benefits of non-marketed goods so

Table 2 Estimated expected benefit of mitigation measures against T-year or severe event

T, year	N, year	r	B_e, US$$10^9$
10	10	0.05	16
100	10	0.05	1.6
100	50	0.05	3.8
100	100	0.05	4.2
100	100	0.03	6.5
100	100	0.01	12.7

that they could be entered directly into cost-benefit calculations and/or (ii) organizing local (national) votes on the urgent projects. Based on their views, the governments should go forward with their final decision concerning the funding of the proposed projects.

2.3 Political factor

The investment to avoid losses tends not to be easily accepted in political decision making as compared with that to gain positive benefits. It is because the benefit of preventing losses, however long lasting it is, is not easily visible while the positive benefit, however short benefit it is, is obvious and can easily be agreed by people. Vit Klemes called this ‘‘Hydro-illogical Cycle’’ (the term used in drought research; Tannehill 1947), meaning that a large investment (peak discharge) is made when a big disaster (rainfall) occurs and the investment (discharge) decreases till the next disaster (rainfall) occurs. The reaction of media and the societal attention to disasters follow the same cycle.

The delay in preparedness investment is a matter of political decision. The investigations (and the report) by the House of Representatives show that the tragic aftermath of hurricane Katrina was a failure of the governmental initiative. The report mentions that U.S. disaster preparedness remains dangerously inadequate (Hsu 2006).

Poor people are living in a low safety area. Their political influence is much lower than the rich people's as they have little power in economy. Although they have equal vote, they do not have equal voice in their state parliament and federal congress. Political decision reflects the views of a majority of the ruling population. Fairness and equity seem not necessarily unquestionable even in the most democratic countries.

Politicians fund where people (especially politically influential people) wish. In the case of President Bush, the choice was to wage war, as happened in a number of cases in the history. Disaster prevention makes sense only in peace. More people have been, and are being, killed by people rather than by any natural disasters. More economic properties have been taken away by people rather than by natural disasters. People can live outside of natural risk areas but not outside of war risk areas. After the Great 1755 Lisbon Earthquake Immanuel Kant, a famous German philosopher, wrote to King Friedrich II while the 7 years war was already impending, in short: ‘‘Sire, we cannot yet prevent an earthquake, but you can prevent a war’’ (Kant 1756; Fuchs 2005).

2.4 Factor of preparedness and awareness

The level of preparedness for the disaster events of December 26, 2004 in all countries affected by tsunami turned out to be extremely low, partly because it happened without any warning. But even if a warning had been sent to the appropriate national authorities, it is unlikely that it would have been delivered to the public on beaches and in waterfront hotels in a timely manner. It is also unlikely that people would have responded to it in appropriate manner, since most of them did not believe that such a disaster could affect them.

Emergency management practices should always be planned and exercised well before a disaster occurs. Human adjustment measures to live with risk are important. Such measures include hazard maps, education and awareness raising, warning, evacuation, levee patrol, emergency protection, periodical exercises of evacuation, etc. The major emphasis should be *where* and *how* to evacuate. This was the main fault in the New Orleans case. As a result of low preparedness and awareness, a hundred-km-long line of private cars moving out of Houston (to escape the Rita hurricane) was blocked up at the regional highways. Such measures apply not only to hurricanes, tsunamis or floods but also to earthquakes, volcanic eruptions, landslides, debris flows, fires and any other disasters. Scientists can help with the design of emergency management plans and practices. For example, there are many hazards and risk maps available in many countries and regions on earthquakes, volcanic eruptions, floods, landslides, hurricanes, and other natural disasters (e.g., http://www.ngdc.noaa.gov/seg/hazard/hazards.shtml). The maps change with time, specifically in big cities and coastal regions, and there is a need to proceed to georisk monitoring. Therefore, research on time-dependent hazard, vulnerability and risk is essential to update periodically natural hazard and risk maps.

If the concern of the low-land soup bowl area (in the case of New Orleans) was made even more widely and strongly aware in the local community as well as the nation by local government, schools, media, NGOs etc., preparedness and other preventive actions might have been put forward. It is clearly observable that there were a number of wise alerts and proposals made related to this area but they were submerged under other matters like wars, political affairs, environmental issues and other social affairs. Without having the scientific awareness raised, no political and governmental actions are possible. Here there is a large room for geoscientists to take responsibility.

3 Role of geoscience in preventive disaster management

The vulnerability of our society to geophysical and geological disasters is rapidly growing due to increasing industrial and population density in the hazard-prone regions, especially in coastal areas. Despite the Aceh-Sumatra 2004 earthquake and tsunami being devastating, there are several other places on our globe which can be affected much more disastrously: Tokyo, San Francisco, Los Angeles, and some others (Munich Re 2004). ‘‘Today a single earthquake may take up to a million lives; cause material damage up to a $\$10^{12}$, with a chain reaction expanding to a world-wide economic depression (e.g., if it occurs in Tokyo); trigger a major ecological catastrophe (e.g., several Chernobyl—type calamities at once); raze a megacity; disrupt the military balance in a region (e.g., if it occurs in the Dead Sea rift zone)’’ (Keilis-Borok 2003). In the case of water-related hazards the recurrence frequency of extreme events is higher than that of earthquakes. As a result, the average number of annual deaths (about 25,000 people) is the highest in natural hazards (UNU 2004).

How to convince disaster-management authorities paying forward, in advance of rare extreme events, to mitigate or even to prevent in some cases inflicting humanitarian disasters? What is the role of geoscientists in preventive disaster management of catastrophic events?

Science should become the *brain* of the preventive disaster management. One of the primary roles of geoscientists is to enlighten society on urgent problems of geohazards and risk and to assist disaster managers in terms of timely delivery of reliable forecasts on extreme events and on their possible aftermath. While extreme events and their effects are rare in the experience of individuals (sometimes even societies), geoscientists should interpret the past observations and translate the available experience from one generation to another, hence reducing the impact of the rarity of the events.

At present, the role of science is limited by inaccurate (in a deterministic sense) predictions of extreme events. But this fact should not push geoscientists to give up the predictions of extreme events. They can enhance the study on temporal and spatial accurate prediction of the events, that is, prediction of the two important parameters for preventive disaster management: *where* and *when*. Meanwhile, to make a great advance in natural disaster-related research, science needs a *major investment* and other stakeholders in relation to disaster management (e.g., government, industry, banks, and insurance) should consider possibilities for a large investment in such research and in preventive disaster management. The insurance industry seems to be ready to take a role in the implementation of preventive measures to reduce the aftermaths of extreme natural events. ''The frequency and scope of loss of major natural catastrophes will continue to increase dramatically throughout the world. Unless drastic measures are taken soon to prevent it, this trend will be intensified considerably by the ever more evident warming of the atmosphere, the resultant increase in sea level, and the intensification of storm and precipitation processes. In its own interest, the insurance industry must assume a major role in implementing preventive measures in order to ensure that it can provide cover for natural hazards over the long term'' (Berz 2004).

After the 2004 Aceh-Sumatra catastrophic event, the IUGG Commission on Geophysical Risk and Sustainability proposed to set up regional Disaster Management Centers in order to monitor land, ocean, and atmosphere in relation to all kinds of natural hazards and risks, especially those related to coastal regions, since we now have evidence of a strong coupling between land-ocean-atmosphere. Moreover, the Commission recommended to develop multidisciplinary and multinational research programs and networks on geophysical hazards and risks in the affected countries in order to integrate diverse data streams, to improve understanding of the natural phenomena associated with the disasters, to enhance predictive modeling capability, and to generate and to disseminate timely and accurate information needed by decision makers and the public (IUGG GeoRisk Commission Statement 2005).

4 Conclusion

Scientists must act today and implement state-of-the-art measures to protect society from rare but recurrent extreme natural catastrophes. Otherwise we will witness again and again the tragic aftermaths of disasters, which could have been avoided. ''Of course, things are complicated . . . But in the end every situation can be reduced to a simple question: Do we act or not? If yes, in what way'' (Burdick 1964).

''Protecting human life and property requires an uninterrupted chain of links: from monitoring and detection, through interpretation and forecasting, public awareness and response measures, to response and mitigation of the effects. The chain is only as strong as its weakest link!'' (Uri Shamir, pers. comm., Sept. 2005)

And peace, fairness and equity are prerequisites in preventive disaster management. Continuous investment is necessary in good balance with structural measures and non-structural measures to live with natural disasters. Evacuation and refugee management should be the top priority anywhere in the world. Continuous alert on disaster is absolutely necessary and geoscientists are ready to take a considerable part of responsibility.

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