THE HAZARDOUS EARTH

Bill McGuire
University College London, UK

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Summary

As the world's population grows, there is an ever-increasing pressure to utilize land exposed to extreme geological hazards. Earthquakes, volcanic eruptions, landslides, and floods already cause annual economic losses of at least several tens of billions of US dollars, before account is taken of lives lost. This cost will inevitably increase unless governments can be forced to give a higher priority to public safety and to the implementation of protective measures.

1. Introduction

Earth is unquestionably a hazardous planet on which to live, and is likely to become even more dangerous in this century. A recent report by the reinsurance company Munich Re. estimates that up to 15 million people were killed by natural hazards in the last millennium (Table 1), and over 3.5 million in the twentieth century alone. Despite our modern technology and somewhat improved forecasting methods there remains little prospect that our world will become any safer in years to come. Although there are differences from year to year in the cost of natural disasters, the trend is ever upward as more and more of Earth's remorselessly increasingly population becomes vulnerable to earthquakes, volcanic eruptions, landslides, floods, and windstorms. One of the worst years in recent times, 1999, provided a snapshot of the threat from geophysical hazards that is part of everyday life for many people across the planet. Earthquakes in Turkey, Taiwan, and Colombia, together with terrible landslides in Venezuela and storms and floods in Europe and India and Southeast Asia contributed to economic losses totaling US$100 billion and the loss of over 75 000 lives.

Mounting evidence points to increasing numbers of meteorological hazards such as cyclones, tornadoes, and floods because of global warming, but the number of

geological hazards such as earthquakes and volcanic eruptions remains constant. The problem is not, therefore, that there are more earthquakes or eruptions but that more people are now being affected. One of the main reasons for this escalating tectonic threat is increasing urbanization. For thousands of years most of our ancestors lived in rural circumstances, with the growth of cities being regulated by disease, and as recently as 1600 only a handful of cities had populations of over 200 000. Now, however, there are 27 megacities—with populations in excess of 8 million—and over 140 supercities holding over 2 million people, most of them located in poor, developing countries prone to natural hazards. Within a few years, for the first time in history, more people will live in urban environments than in the countryside, and by 2025 over 5.5 billion people will be crammed into gigantic sprawling cities—more than the entire population of the planet in 1990.

Many of these huge urban agglomerations—such as Mexico City and Tokyo—are located close to plate boundaries or other tectonically active structures, where destructive earthquakes and volcanic eruptions are prevalent. The situation represents a catastrophe waiting to happen, and before very long either a major ‘quake or a powerful eruption is going to score a direct hit on a poorly constructed megacity and its ill-prepared population. The outcome will be far more dreadful than any natural disaster the planet has so far experienced. Over the past 1000 years, earthquakes have caused nearly 8 million deaths. The ever-growing megacities, however, pose major new targets, and it would be no surprise if, within the next few hundred years, 3 million urban dwellers were wiped out in a single massive ‘quake. The threat from volcanic eruptions is barely less, and over 500 million people—one in six of Earth’s population—now inhabit the danger zones around active volcanoes. Unlike earthquakes, a major volcanic eruption can also impinge upon the population of the entire planet through its impact on the climate, and knock-on effects can severely damage both harvests and health.

Although volcanic eruptions and earthquakes grab the limelight, landslides also exact a devastating toll in terms of lives lost and damage caused. Because they are often secondary events—triggered, for example, by earthquakes or floods—their impact is often grossly underestimated, and over half the deaths in Japanese earthquakes during the last 35 years was caused by landslides. More recently, in 1999, torrential rains associated with Hurricane Mitch initiated about a million landslides in the Central American state of Honduras. As urbanization increases and steeper marginal land is occupied by dwellings, it is likely that death and destruction resulting from landslides will also rise dramatically.

Year	Country	Event	Fatalities
526	Turkey	Earthquake	250 000
1290	China	Earthquake	100 000
1303	China	Earthquake	200 000
1556	China	Earthquake and landslides	830 000
1622	China	Earthquake	150 000
1731	China	Earthquake	100 000
1737	India	Tropical cyclone	300 000
1815	Indonesia	Volcanic eruption and following famine	90 000
1850	China	Earthquake	300 000

1883	Indonesia	Volcanic eruption and tsunami	36 000
1902	Martinique	Volcanic eruption	29 000
1923	Japan	Earthquake and fire	142 000
1939	Turkey	Earthquake	362 740
1970	Peru	Earthquake and landslide	67 000
1976	China	Earthquake	290 000
1985	Colombia	Volcanic eruption triggered mudflow	23 000
1999	Venezuela	Landslides	~50 000
2001	India	Earthquake	<100 000

Table 1. The world's greatest geological catastrophes

2. The Scale of the Threat from Geological Hazards

The Earth is almost constantly shaking, and over half a million 'quakes are measured every year—more than one a minute. Fortunately, over 99 percent of these are too small to be damaging, and most are so weak that they can only be detected by sensitive seismographs. More than half of the remaining 1 percent of earthquakes, however, are large enough to cause concern and some damage, and about nine of these occur every day, almost anywhere on the planet. Usually the resulting damage is minimal—limited to smashed crockery, broken windows, and cracked walls—and serious injury or death are rare. Severe problems do not really start until 'quakes reach Magnitude 6 on the Richter scale, but such large events are normally confined to plate margins. An earthquake on this scale shakes the planet about once every three days, and can cause extensive damage and loss of life. Its impact, however, depends very much on which part of the world it strikes. In California, where seismic building codes are stringent and strongly enforced, a Magnitude 6 earthquake would cause little damage and probably no loss of life. A similar sized 'quake hitting a crowded and poorly constructed city in a developing country could, in contrast, cause severe damage and take thousands of lives.

Volcanic eruptions cause less damage than earthquakes but their impact can be devastating to the half a billion people who now live in the danger zones around active or potentially active volcanoes. Historical records exist for eruptions at 539 volcanoes, but the true number of active volcanoes is probably much higher. Over 1500 volcanoes have erupted since the end of the last Ice Age around 10 000 years ago, and all are likely to erupt again. Some volcanoes, such as Stromboli and Etna (Italy) or Kilauea (Hawaii), are in almost constant eruption, and in an average year a total of about 50 volcanoes will burst into life. Although volcanoes are responsible for fewer deaths than earthquakes, they nevertheless inflict a terrible toll. Since the end of the eighteenth century alone, volcanic disasters have killed over 230 000 people and injured many thousands of others.

Both large earthquakes and volcanoes are intimately linked with the system of rocky plates that form the outer carapace of Earth, and tend to be confined to the margins of these plates rather than their relatively stable interiors. Destructive earthquakes occur mainly where two plates scrape past one another along crustal weaknesses, such as the San Andreas Fault in California (for example, the Loma Prieta earthquake in 1989 and Northridge in 1994) and the North Anatolian Fault that slices through northern Turkey

(for example, the Izmit ‘quake of 1999). They also occur where one plate is either colliding with or plunging beneath another, such as, respectively, the zone of high seismic risk that stretches across northern India, and the ‘quake-prone regions that surround the Pacific Basin. Some of the largest earthquakes ever recorded have occurred at the Pacific margin *subduction zones*, where an oceanic plate made up of dense basalt drops back into the Earth’s interior beneath a continental plate made up of lower density granitic rock. This occurs all around the Pacific Rim, triggering major destructive earthquakes such as those that hit Chile (Magnitude 8.3) in 1960, Alaska (Magnitude 8.4) in 1964—two of the greatest earthquakes of the twentieth century—and, more recently, Kobe in Japan (Magnitude 7.2) in 1995.

The world’s most dangerous and explosive volcanoes are also associated with subduction zones, with the great majority of highly destructive eruptions occurring where subduction is taking place around the Pacific Rim, in Southeast Asia, and in the Caribbean. Recent examples include Unzen (Japan) and Pinatubo (Philippines) both in 1991, Rabaul (Papua New Guinea) in 1994, and Montserrat (Caribbean), which has been in eruption since 1995. Exceptions do exist, however, and some of the world’s most active volcanoes occur in so-called “intraplate” settings that are remote from plate boundaries. Fortunately, however, intraplate volcanoes are rarely as dangerous as their seismic counterparts. Probably the best known of all intraplate volcanoes are those that make up the Hawaiian–Emperor chain of islands in the center of the Pacific Ocean. These volcanoes have been generated by what is known as a “mantle hotspot”; a finger of hot mantle that touches the cold brittle lithosphere above it and effectively melts its way through. Although the hotspot stays put, the Pacific Plate moves over it at a rate of about nine centimeters a year. In fact the plate has been trundling slowly over the hotspot for the past 80 million years, leaving a chain of volcanic islands now 6000 kilometers long. Currently the big island of Hawaii lies above the hotspot, as indicated by its two currently active volcanoes, Mauna Loa and Kilauea, the latter being one of the most active in the world. Although they occasionally burn parts of forests and bulldoze down a few houses, the lava-dominated eruptions of the Hawaiian volcanoes are not a major hazard, and this is typical of most intraplate, hotspot-related volcanoes. Exceptions include three gigantic “super-eruptions” that blasted giant volcanic craters—known as *calderas*—in the Yellowstone Park region of Wyoming (United States) three times over the last two million years. Other intraplate volcanoes that have damaging eruptions include the effusive Mount Etna in Sicily, as well as Vesuvius in the Bay of Naples (Italy) that, following some 300 years of nearly continuous eruption, has been ominously quiet now for over 50 years.

Earthquakes also occur within the interiors of the plates, where there are deep faults that move only very occasionally. The problem is that when they do move, perhaps after centuries of inactivity, the release of the huge accumulated strain can generate some of the largest and potentially most destructive earthquakes known. To compound the situation, because of the long gaps between movements along such faults, local populations are typically not geared up to expect an earthquake, buildings are rarely built to withstand the shocks, and the authorities are often unprepared for coping with the devastation.

The classic example of a destructive *intraplate* earthquake occurred almost 200 years ago right in the heart of the United States. In 1811, what may have been the most energetic earthquake in the history of the country shocked the sparse population of New Madrid in Missouri. Although it is difficult to get an accurate estimate of the strength of the ‘quake (or, more accurately, series of ‘quakes) because there were few buildings available on which to measure its effects, it was powerful enough to cause significant structural damage in Washington, D.C., Pittsburgh, and the coast of South Carolina, and to be felt nearly 2000 km away in Boston. Unlike the example of the San Andreas Fault in California, no fault traces are visible at the surface in New Madrid. Clearly, however, a fault must lie at depth and, despite another smaller ‘quake in 1895, this has been accumulating strain over the past 190 years. Without question there will be a major earthquake in this region again, and the impact will be devastating in urban areas made up of buildings that are simply not constructed to withstand the severe ground shaking that will occur. The most recent major intraplate earthquake struck the region of Bhuj in the Indian state of Gujarat in January 2001. This devastating event completely destroyed around 400 000 buildings, and unofficial figures suggest that the death toll might have been as high as 100 000.

Landslides are ubiquitous and can occur anywhere on the planet where there is a sufficient slope to permit mass movement. Many landslides are relatively small and constitute only a temporary inconvenience—through blocking roads or railway lines—rather than a major threat. On occasion, however, they can involve the collapse of at least hundreds of millions of cubic meters of rock, and devastate entire communities without warning. Most large landslides are generated in regions of steep, elevated terrain such as the Himalayas and Andes, which are also prone to earthquakes and heavy precipitation. They can also be triggered by volcanic activity, as demonstrated by the spectacular and lethal collapse of the north flank of Mount St. Helens (Washington State, United States) in 1980. In fact, some of the greatest landslides ever recorded (involving thousands of cubic kilometers of material) have occurred during prehistoric times, when the flanks of ocean island volcanoes collapsed in the Canary and Hawaiian archipelagoes, generating huge tsunami which, if they occurred today, would cause devastation along the rims of their ocean basins.

Year	Volcano	Deaths	Injuries	Cause
1991	Pinatubo (Philippines)	800	Many	Mudflows and disease
1986	Lake Nyos (Cameroon)	1700	300	Carbon dioxide gas release
1985	Nevado del Ruiz (Colombia)	23 080	10,000	Mudflows
1983	El Chichón (Mexico)	1879	?	Pyroclastic flows
1951	Mount Lamington (Papua New Guinea)	2942	18	Pyroclastic flows
1919	Kelut	5110	?	Mudflows and

	(Indonesia)			pyroclastic flows
1902	Mont Pelée (Martinique)	~29 000	2	Pyroclastic flows
1902	Santa Maria (Guatemala)	~2000	?	Ashfall
1888	Ritter Island (Papua New Guinea)	~3000	?	Tsunami
1883	Krakatoa (Indonesia)	36 417	Many	Tsunami and pyroclastic flows
1822	Galunggung (Indonesia)	4011	?	Pyroclastic flows
1815	Tambora (Indonesia)	92 000	Many	Pyroclastic flows, ashfall, famine and disease
1792	Unzen (Japan)	14 524	?	Tsunami
1783	Laki (Iceland)	~10 000	?	Famine
1631	Vesuvius (Italy)	>4000	Many	Pyroclastic surges, ashfall and mudflows
79 AD	Vesuvius (Italy)	>3500	?	Pyroclastic surges

Table 2. Deaths and injuries from volcanic eruptions

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Bibliography

Adams J. (1995) *Risk*, 192 pp. London: UCL Press. [Examines risk as a matter of perception.]

Alexander D. (2000). *Confronting Catastrophe: New Perspectives on Natural Disasters*, 288 pp. London: Terra Publishing.

Bell F. (1999). *Geological Hazards*, 656 pp. London: Spon Press.

Bryant E.A. (2001). *Tsunami*.350 pp. Cambridge: Cambridge University Press.

Bolt B. (1999) *Earthquakes*, 377 pp. (Fourth Edition). Basingstoke, UK: W.H. Freeman.

Keating B.H., Waythomas C.F., and Dawson A.G. (eds.) (2000). *Landslides and Tsunami*, 324 pp. Berlin: Birkhäuser Verlag. [A compilation of recent research on tsunami triggered by landslides.]

McGuire W.J. (1999). *Apocalypse: A Natural History of Global Disasters*, 256 pp. London: Cassell.

Scarpa R. and Tilling R. I. (eds.) (1996). *Monitoring and Mitigation of Volcanic Hazards*, 910 pp. Berlin: Springer Verlag. [A comprehensive review of methods for monitoring volcanoes and mitigating their hazards.]

Sigurdsson H., (ed.-in-chief) (2000) *Encyclopedia of Volcanoes*, 1000 pp. London: Academic Press.

Turner A.K. and Schuster R.L. (eds.) (1996). *Landslides: Investigation and Mitigation. Transportation Research Board Special Report 247*, 346 pp. Washington, D.C.: National Academy Press. [The practice of monitoring unstable slopes and mitigating their hazards.]

Biographical Sketch

Bill McGuire is Benfield Greig Professor of Geophysical Hazards and Director of the Benfield Greig Hazard Research Center in the Department of Geological Sciences at University College London. He is an expert on global geophysical events, with a particular interest in volcano monitoring and volcanic hazards.