NATURAL HAZARDS

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Summary - The Unquiet Earth

Brevis ipsa vita est sed malis fit longior
Our life is short but is made longer by misfortunes (Publilius Syrus)

Natural hazards are extreme phenomena that threaten human social, economic and environmental systems with exceptional loss or casualties. They range from sudden-impact events, such as earthquakes and lightning strikes, to slow-onset phenomena such as desertification and accelerated soil erosion. Hazards act upon human vulnerability to produce risk which translates into losses (casualties, destruction and damage) when disaster occurs. The primacy of vulnerability makes 'natural hazard' something of a convenience term, given that the resulting disasters are very much the result of human risk-taking. Risk is tempered by the exposure of populations and the built environment to hazards, by the release rate of hazardous events and by the dose rate with which risk-takers suffer impacts and losses. Natural hazard risks are also subject to potential misestimation owing to a variety of perception factors. In this context, the profiles of risk-takers and risk-evaders are well-known, but attitudes to natural hazard risks also depend on the way that these are communicated to the public and to stakeholders. The combination of objective risk, perception and associated decision making defines the disaster potential of a natural hazard.

Natural hazards are classified according to the geophysical phenomena involved and the speed of impact (from instantaneous to slow onset). Earthquakes are the archetypical sudden-impact disaster, and are seldom preceded by short-term warnings, while desertification is a typical form of slow onset or 'creeping' disaster. Volcanic eruptions involve often more complex patterns of onset and impact, and can last for months, years

or intermittently even for centuries. Very large floods, eruptions or meteorite impacts may be termed catastrophes but they cannot be prepared for in the same manner as smaller, more frequent events and so are not treated as being in the same category of hazard.

Natural hazards tend to be repetitive events and so are tackled with a series of measures that can be termed the 'disaster cycle': risk reduction in times of quiescence; and in times of danger, warning and readiness, emergency action (including the rescue of survivors and mass-casualty management), recovery and reconstruction. Recovery from disaster depends on the available resources and the geographical and political connectedness of communities. Particular problems arise in the modern 'complex emergency', in which natural hazards are only one of a series of problems that includes the breakdown of civil society and civil warfare, insurgency or 'warlordism'.

Natural hazard risk reduction and mitigation should be incorporated into post-disaster reconstruction and should be a part of the development of sustainable communities. Mitigation can be classified as structural (e.g., engineering construction), semi-structural (e.g., flood-proofing buildings), and non-structural (e.g., emergency planning, land-use control and insurance). Typically a country will pass from reliance on purely structural measures, as its first approach to natural hazard abatement, to dependence on a diversified series of structural and non-structural measures. Reliance on insurance is increasing, but liability problems and shortage of capital are reducing the effectiveness of this option. As non-structural mitigation gains in importance, national and international institutions are being strengthened, although rather slowly. So far they have had relatively little impact on the crucial problem of reducing poverty in order to increase community resistance to natural hazard impacts.

1. Introduction - What is A Natural Hazard?

Natural hazards are naturally occurring geophysical phenomena that in their extreme forms threaten life or property. They occur in the lithosphere (e.g., earthquakes), atmosphere, (e.g., storms), hydrosphere (e.g., floods) or biosphere (e.g., locust infestations). Many of them can be considered resources in their less extreme forms, but hazards when they exceed certain thresholds defined with respect to their impacts upon human or environmental systems. Thus water is a life-sustaining commodity, but in abundance it can result in floods, while in unanticipated shortage it can cause droughts. Many parts of the world have meteorological and hydrological regimes that are subject to extremes which allow scarcity and excess to alternate: in the tropics, for example, floods and droughts may follow each other, as happens periodically in countries like Bangladesh and Ethiopia.

Global climate change has not yet led incontrovertibly to an increase in the physical strength or frequency of natural hazards, but eventually it will probably result in more powerful storms, more abundant surface runoff of water, and longer periods of drought--i.e. more extreme meteorological hazards. This is worrying, because the casualties and damage caused by storms and floods are non-linearly related to nature's kinetic energy expenditure, such that very large events cause disproportionately greater losses. On the other hand, global change in human systems has already resulted in a considerable increase in vulnerability to natural disaster. Factors resulting in the growth of vulnerability include high rates of population growth, rapid urbanisation of hazardous areas (such as coasts that suffer storm surges and steep slopes that undergo mass movements) and the mushrooming expansion into hazardous terrain of the world's largest cities.

When dealing with the physical phenomena that cause disaster, it is important to remember that they only qualify as hazards if they threaten a human system. For example, the Blackhawk landslide occurred in the Mojave Desert of the southwest USA during prehistoric times. Some 282 million cubic metres of rock slid downslope at an estimated speed of up to 235 km/hr and the resulting deposit covered 14 sq. km, but it was a mere geological curiosity, not a hazard, as no human population or use of the land was involved. In contrast, the debris flow that occurred at Aberfan, South Wales, in 1966 moved at walking pace a short distance down an artificial mound of colliery spoil, but it demolished parts of two schools and killed 144 people, 116 of them children between the ages of 7 and 9. Thus a hazard resulted in a disaster.

Experts have not reached complete agreement on the meaning of the term disaster (Quarantelli 1998). Here, it will be considered synonymous with catastrophe and calamity, even though some authors regard these words as descriptive of different intensities of impact or states of emergency. Although several scales representing the magnitude of disaster impact have been published, they have not been generally accepted by scientists, scholars and emergency managers. Nevertheless, it is generally agreed that an incident does not exceed society's ability to cope with it using normal resources, whereas a disaster or catastrophe does.

According to data from the Red Cross and Catholic University of Louvain, about 220 natural disasters occur each year, with a death toll of about 145,000 people and an average of 4.75 million affected. However, it should be borne in mind that disaster data suffer from poor reporting and possibly changeable criteria used in their collection. Moreover, the pattern of events is erratic from year to year. Nevertheless, natural hazards tend to reap their greatest toll in the world's poorer and most populous countries, and particularly in China, India, Bangladesh, the Philippines (which suffers between 20 and 30 typhoons per year), and Indonesia.

The next three sections will consider the fundamental ingredients of the theory of natural hazards: vulnerability, risk and disaster.

2. Vulnerability--The Fundamental Counterpart of Hazard

As noted above, anthropocentrism is a hallmark of natural hazards--i.e. the ability to produce a disaster in human terms. This leads to one of the fundamental relationships of the hazards field

hazard x vulnerability = risk --> disaster

Vulnerability can be defined as susceptibility to disruption or harm, or in quantitative terms as the possible magnitude of losses. As in the science of mechanics friction is mobilized by a force acting on two surfaces, so vulnerability is brought into play by the presence of a hazard that threatens the human system in its physical, social, economic and cultural forms.

Risk is thus the product of hazard and vulnerability. It is an essentially hypothetical quantity, in that it can only materialise in the form of disaster impacts (see above equation). An early and much quoted formulation of natural hazard risk is that offered by the Office of the UN Disaster Relief Co-ordinator (UNDRO) in 1982:-

$R_t = E.R_s = E(H.V)$

E = elements at risk (population, built environment, economic activities, etc.)
R_s = $(H.V)$ is specific risk
H = natural hazard
V = vulnerability

This formulation aims, wherever possible, to quantify risk by examining the specific elements that go to make up a vulnerable community or society. These can be listed as the built environment (vernacular housing, engineering structures, infrastructure and lifelines), communication systems, economy and commerce, and society and culture.

Orthodox ways of using this model tend to assume a linear relationship in which a physical hazard acts upon a vulnerable society to produce the impact of disaster. However, since the 1970s, an alternative approach has also been followed in which vulnerability is considered to be more significant in explaining disaster than are the manifestations of physical hazards, which are regarded almost as mere triggers. In this formulation, emphasis is placed upon the feedback that occurs between vulnerability and natural hazards: in any juridical sense, and most practical ways, natural hazards are no longer considered to be inevitable 'acts of God', but are the result of risk taking in human societies, or at least of the failure of protect ourselves adequately. Thus, 'natural hazard' is a convenience term, not an accurate descriptor, as it should not imply that people, communities and society are exonerated from responsibility for risk taking.

Alexander (2000) further differentiated vulnerability on the basis of how it is tackled by society. Pristine vulnerability is determined by lack of experience of hazards and involves no particular attempts to protect society against them. Positive vulnerability is determined by loss propensity alone and is usually connected with the mitigation of hazards by building engineering structures, such as anti-seismic buildings or raised river banks that protect against flooding. Deprived vulnerability occurs when the result of research are not diffused or utilized sufficiently, a very common circumstance in which the technical know-how to reduce risks is available but for lack of money or organisation it is not utilised. Finally, wilful vulnerability occurs when the technical knowledge of how to reduce risks is deliberately ignored, perhaps as a result of corruption or negligence. As Burton *et al.* (1993) pointed out, when hazard impacts reach a certain level of seriousness and repetition, society crosses a threshold of loss tolerance (a threshold of acceptable vulnerability) and a new consensus emerges about what level of vulnerability is acceptable.

Capability, the inverse of vulnerability: Approaches to natural hazard vulnerability can be divided into those that enquire into it to estimate risk, as in the UNDRO equation given above, and those that look at the converse, which is known as capability, capacity, coping or resilience:

Risk = [hazard x vulnerability] - capability

Natural hazards tend to be repetitive events and most societies afflicted by them have evolved mechanisms to avoid or reduce the impacts. Thus the rice farmers of the Ganges-Brahmaputra delta have planting and harvesting strategies for exploiting the seasonal flooding that fertilises their paddies with organic nutrients, but they also have strategies for reducing the impact of contingent flooding that can destroy crops by inundating them with stagnant water. In a very different context, the U.S. Weather Service has invested heavily in Nexrad Doppler radar systems that can track tornado-producing thunderstorms. This enables warnings to be given 20-120 minutes ahead of deadly tornado strikes. Thus on Monday 3 May 1999 when 76 tornadoes struck Texas, Oklahoma and Kansas, including a magnitude F5 storm (with rotational wind speeds of 410-520 km hr^{-1} and a path of devastation extending 130 by 1.5 km), timely warning kept the death toll as low as 44, even though the winds destroyed 4319 buildings. However, it is an important principle in the world's poorer hazard zones that imported coping mechanisms should not drive out indigenous ones that have produced tried and tested results. If this happens, then a dependency on technology or imported management styles can evolve that is dangerous when these are not entirely reliable.

3. Risk - The Product of Hazard and Vulnerability

When a geophysical phenomenon threatens something, a risk of disaster exists. This can be estimated by combining the *probability* of natural hazard events of given sizes and the *consequences* (usually conceptualised as losses) that would arise if the events take place during a given period of time. The probability distribution of events represents the frequency with which the hazard strikes and is sometimes termed, by analogy with nuclear radiation emissions, the release rate. For example, as high pore-water pressure in soils is one of the main mechanisms that set off landslides, these are generally seasonal phenomena, and release is concentrated in periods of high precipitation and saturation of the ground. For example, in November 1994 Tropical Storm Gordon caused excess runoff that destabilized slopes in Haiti and killed 750 people.

Another fundamental variable is exposure. A person who lives and works in a seismic zone is more or less constantly exposed to the risk of injury in an earthquake, though research suggests that for the majority of inhabitants of the world's seismic areas, exposure to the risk is greatest at night: although the distribution of earthquakes is not affected by time of day, vernacular housing is particularly at risk in countries such as Italy, Iran, China and Afghanistan, and people are less ready to take self-protective action when they are asleep. Worldwide, between 50 and 95 per cent of deaths in major earthquakes occur between midnight and 6 a.m.

Exposure can also be treated quantitatively. If we consider the case of a person who passes on his way to and from work for ten minutes a day, five times a week, along a stretch of road that is threatened with rockfalls, this person's exposure to the risk of being hit by falling rock, or driving into fallen rocks, is 10 x 5 ÷ 60 ÷ 24 ÷ 7 = 0.005 of the week, which expresses the vulnerability of an element at risk per unit time, but not the degree of risk. If a householder can expect to suffer landslide damage once in a lifetime, then he or she bears a risk of approximately 1/80yr (0.0125 year), which can be described, again by analogy with nuclear radiation measurements, as the dose rate, or impact per person (or per house). Where landslides occur every winter during the season of greatest precipitation, the dose rate for buildings, roads or agricultural land can be quite high (Figure 1).

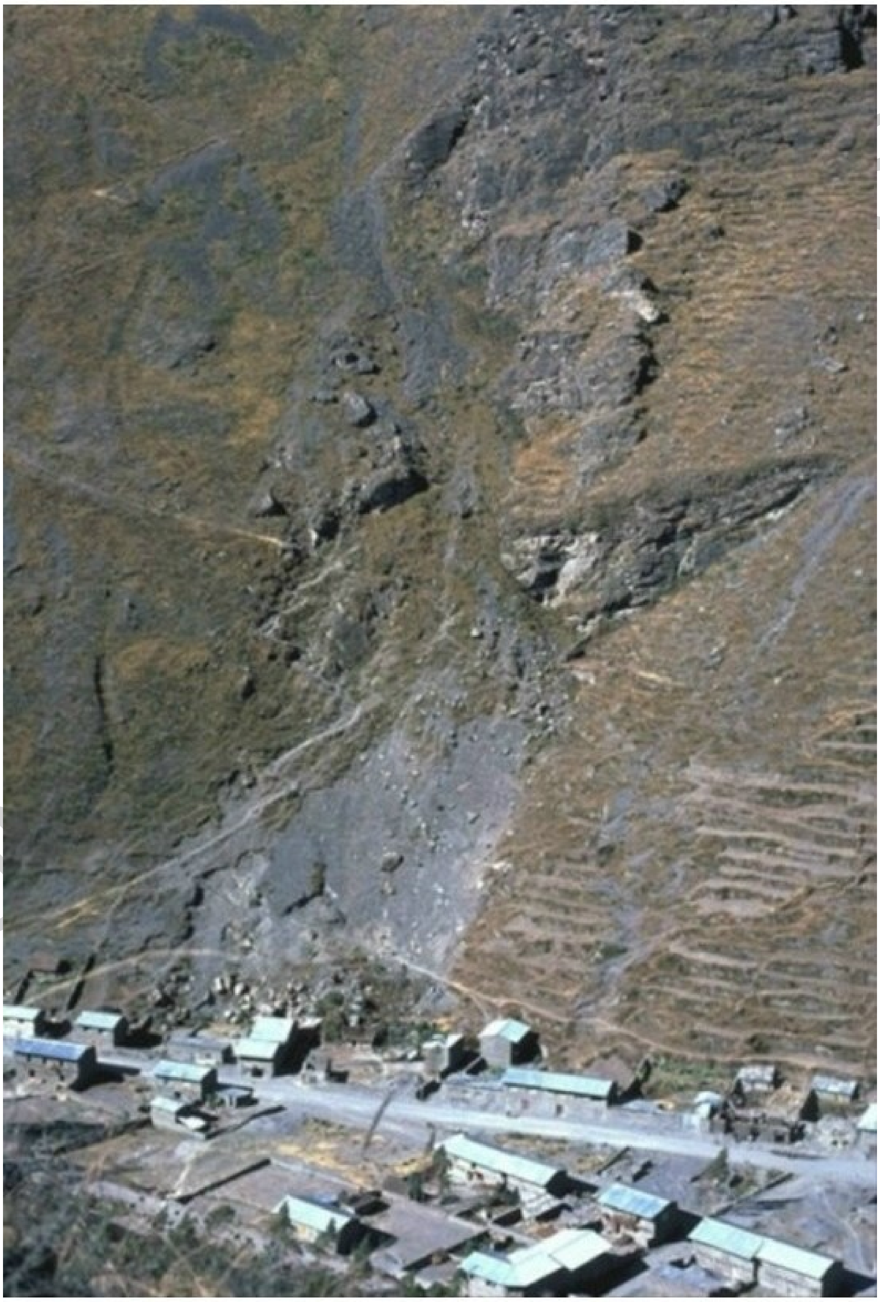

Figure 1: Landslide damage to houses and a road in the Andes of Southern Peru

It should be noted in passing that the concept of exposure is different in the insurance industry, which defines it as the extent of possible claims when hazards cause major losses, and hence relates it to questions of financial liability.

Natural hazard risk analysis involves identifying, estimating, measuring and evaluating risk. There has been considerable debate between engineers and social scientists about whether natural hazard risk can profitably and successfully be quantified; indeed, whether it is necessary to quantify it at all.

Engineers and earth scientists tend to regard risk analysis as a formal means of quantitatively evaluating the likelihood of a set of disaster outcomes, which they accomplish by assigning probabilities to the events. Social scientists argue that risk need not be quantified to be analysed and that it is often sufficient to conceptualise a risk in order to understand its seriousness.

In general types of risk analysis, comparisons are often more meaningful than absolute numbers or probabilities, especially when the values are quite small, for ordinary people--the stakeholders in natural hazard risk abatement--tend not to understand likelihoods expressed as small fractions.

Formal risk analysis is based upon the creation of an ensemble of scenarios which express what might happen as a chain of occurrences. For example, they could describe a period of excessive rainfall, leading to the failure of a slope and damage to a building located upon it. A risk scenario is not intended to be an accurate picture of an inevitable future, nor is it a complete description of the set of possible futures.

It is instead a prediction of the improbable, but nonetheless possible, coincidence of events that could create a damaging impact. This permits the researcher to explore the possibilities for forecasting uncommon events. However, risk scenarios need to be accompanied by assessments of the probability, or at least the generalized likelihood, that they will come true.

These can be compiled using historical data on past disasters, but the results may nevertheless be difficult to couch in terms that would enable a member of the public to decide a pragmatic question such as "should I live in my house if it is located on a potentially unstable slope?" The answer to such a question may depend on an arbitrary tolerance threshold (Alexander 1993, p. 578) that is set in such a way as to manage or cohabit with the risk.

Much of the complexity of risk analysis stems from the interconnection between innate risk and external influences. It cannot, for example, be separated adequately from cultural factors, which have a major effect on the types and levels of risk that people are willing to assume or tolerate.

Further complexity arises from the fact that vulnerability, hazard, elements at risk, exposure, dose rate and release rate are all concepts that bear some degree of overlap, as exemplified by the circle in Figure 2 that groups the concepts of hazard, vulnerability, risk, release rate, dose rate, background levels and exposure.

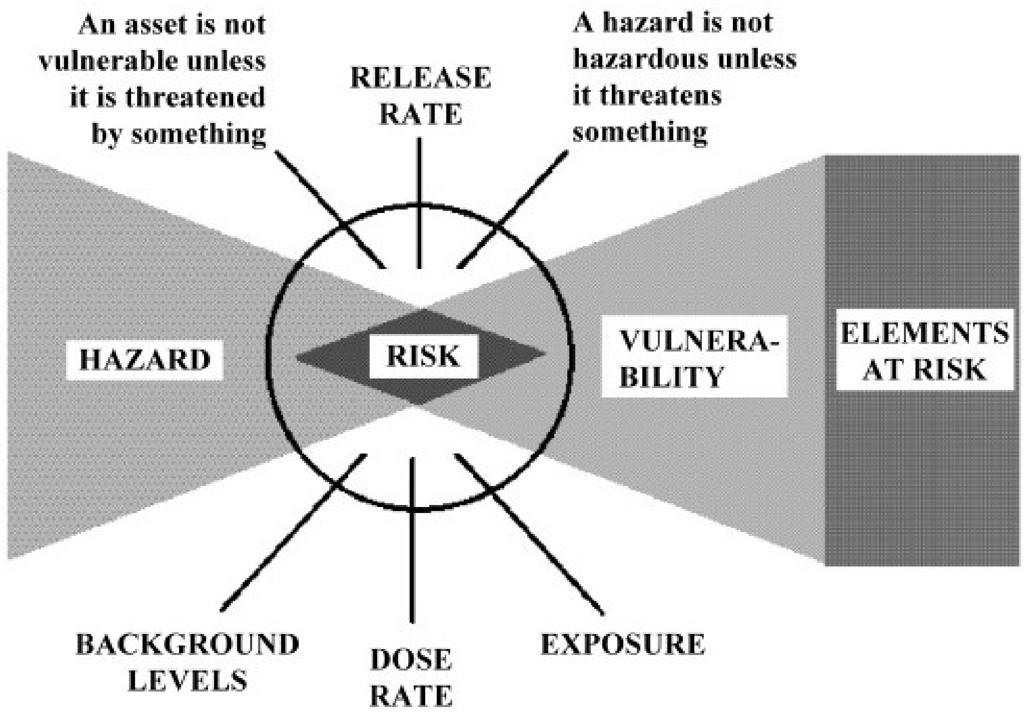

Figure 2: Relationship between hazard, vulnerability, risk and associated concepts.

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