ENVIRONMENTAL HAZARDS AND DISASTER MANAGEMENT

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Contents:

Summary

In this article the current knowledge of hazards and disaster management is critically reviewed. Topics included here are a) natural and man-induced hazards, b) risk modelling and assessment on extreme and catastrophic events, c) vulnerability modelling and assessment, and d) disaster management cycle – Prevention, Preparation, Response and Recovery (PPRR). Finally reviews of the current problems and the future prospect of disaster management are given.

1. Introduction

Traditionally the study of environmental hazards was embedded in various branches of physical sciences, e.g. meteorology, hydrology, geology, geography and engineering, and social sciences, e.g. human geography, sociology, psychology and health and safety. However, for the last two decades, a multi-disciplinary and integrated approach has been adopted in studying environmental hazards and disaster management. This was partly due to the change of global landscape. With thawing of the Cold war between the West and the East and the falling of the Berlin Wall in 1989, we saw the political, economic and social stability in the West and the rise of the economic powers in the East. Through rapid globalization the West and the East have been getting closer, catastrophes become global in scale, e.g. global warming, pandemic influenza and international terrorist attack. Local problems need global solutions. For example, food insecurity in Russia and China 2010, political crises in North Africa 2011 and earthquake-tsunami-radiation disaster in Japan 2011 are all affecting nearly everyone. Natural and human-induced disasters have become major subjects.

If the twin tower terrorist attack in 2001 was still regarded as an independent anti-US incident; arguably, people were really made awake by the Indonesia Boxing Day tsunami 2004. The attitude towards environmental hazards was gigantically changed. The gruesome pictures of bleeding victims and the disconsolate crying for their beloved ones trapped by the falling rubble in an earthquake attracted voluminous reports by media.

With the aid of internet, people are no longer thinking that environmental hazards are something happening far away from them, or something never affecting someone they know. The ensuing events like Hurricane Katrina 2005, Pakistan Kashmir earthquake 2005, the July 7 bombing in London 2005, Haiti earthquake 2010, Eyjafjallajokull eruptions 2010, Europe snowstorms 2010, the Australian flood and cyclone Yasi 2011, Christchurch earthquake 2011 and Japan disaster (earthquake, tsunami and nuclear plant meltdown) 2011 provide examples for testing the integrated disaster management approaches.

Hazards may be unpredictable but disasters can be avoided. Hazards, risk and vulnerability are key elements for the equation of disaster management. To solve this equation, it is imperative to answer these questions: Is the environment becoming more hazardous? Are disasters really getting worse? What is disaster? Are we becoming more at risk to threat of hazards? Can we define an acceptable level of risk? Is our vulnerability getting higher or lower? How can we quantify vulnerability? Can we eliminate hazards or disasters? How well are we in disaster management? What is the future of our disaster management?

2. Environmental Hazards

Some terminologies have to be clarified. When the nature is in its extreme state but it does not cause any casualties, damage or disruption to people living in the area, we can it a *natural event*. *Hazard* is natural or man-induced processes or events that cause potential losses to human lives, property damage, disruption to normal activities and essential functions of the community and damage to the environment. *Disaster* is an extremely severe hazard that has happened, affecting a significant number of people and activities in an extreme way, accompanied by widespread human, material or environmental losses, that is beyond the ability of the community to cope with. *Catastrophe* is used to refer to disaster that brings huge serious damages and sudden unexpected impacts to people.

The environment provides resources (water, air, fire, mineral and wood), i.e. opportunity, to human beings. However, when the disequilibrium of the nature exceeds the threshold of its natural fluctuation, it can trigger the occurrence of extreme environmental events, hazards, or disasters. Geographically, some hazards are locale bounded (e.g. volcanoes) and some are geographically free (e.g. avian flu). Some hazards are seasonally related. For instance, hurricanes can only occur in summer over the Western North Atlantic Ocean Basin. Some hazards can occur all year round. For instance, landslides can occur in any time of the year. Some hazards are unintentional (e.g. earthquakes) while some are intentional in nature (e.g. terrorist attack).

The impact of hazards (e.g. volcanic eruption) can be direct (physical damage of buildings and contents) and indirect (losses of business, revenue or sales and employment, alteration to the normal operational state of the society), tangible (loss of lives) and intangible (stress and post dramatic disorder, damage to the integrity of the society) (Smith, 2001).

However, the occurrence, impact and management of hazards will be complicated if there are more than one hazard at a time. The hazard coupling can take three different forms: (a) two or more hazards happening at the same time at different locations in the same country which demand same resources for response and recovery (e.g. the Sichuan, Wenchuan earthquake and the flood in South China in May 2008); (b) two or more hazards happening one after another in the same place in which the impacts and damages might be exacerbated and the recovery and reconstruction processes will hence be prolonged (e.g. the Japan disaster 2011, the magnitude 8.9 earthquake at the east of Sendai, Honshu, shook and triggered 22 feet tsunami waves which bulldozed people, cars, boats and houses on their ways on 11th March 2011, and nuclear reactor meltdown and explosions followed); and (c) two or more hazards are interconnected in such a way that primary hazard triggers secondary hazards. The impact of each hazard cannot be simply accumulative. On the one hand, the damage may be less than the total damages if two hazards happening at different times. On the other hand, multiple hazards would drain heavily on the response resources and personnel in emergency and thus exacerbate the consequences.

How can we estimate the impact of hazards? Can we know how many people are killed or affected and how many houses are completely or partially destroyed immediately after the hit of a hazard? In reality, the chaos and breakdown of the societal integrity during a disaster complicate the accounting of damages and casualties. For instance, after an earthquake, some people can still be alive but trapped under the rubble; some escape; some unrecorded by the government may die at the scene; and some are visitors but just unlucky being killed while they are there. For the purpose of requiring and deploying the needed resources and emergency services, it is quite essential to have an estimation of approximate amount of casualties (none, slight, moderate, serious, very serious, collapse), structural damages (no damage, partly damage, completely destroy) and financial losses (direct cost of damage, replacement cost of buildings and infrastructure, economic cost of restoring basic services). However, the financial impact by a disaster is not just the temporary or permanent losses of businesses but also the long-term effect on the trust and reputation of the areas for stable investment. The financial market may also react to the damage of hazards sensitively and negatively in some cases. For example, the capital market in Japan was plunged drastically after the earthquake, tsunami and nuclear reactor disasters in Japan, 2011.

The global datasets of hazard and disaster are documented by international organizations, e.g. Natural Hazards Research and Application Information Centre (NHRAIC), Boulder, Colorado and the Centre for Research on the Epidemiology of Disasters (CRED) (EM-DAT) Belgium, and private insurance companies such as MunichRe (NatCat) and SwissRe (Sigma).

2.1 Natural Hazards

Table 1 shows some common natural hazards, the types of damage and some infamous examples. How severe the impact of natural hazard is dependent upon its predictability (recurrence intervals and future probability), speed of onset, duration of impact, areal extent of damage, intensity/magnitude of impact and cultural preparedness for the event (population vulnerability).

Figure 1 shows the distribution of natural disasters, the number of people killed and affected and the estimated damage between 1900 and 2010. Overall, it is found that the recorded number of natural hazards has been increasing. The number of people affected by disaster is rising. Disasters are becoming less deadly but more costly. The increasing losses and damages by natural hazards can be attributed to a lot of factors. For example, people have more possessions. The 21st Century technology allows us to build in areas which are at risk to natural hazards. The physical science of natural hazards can be found in textbooks (e.g. Hyndman and Hyndman, 2011) and manuscripts on specialized subjects (e.g. Elsner and Jagger, 2009).

2.2 Human-induced Hazards

Table 2 shows some common human-induced hazards, the types of damages and some infamous examples. Figure 2 shows the distribution of technological disasters, the number of people killed and affected, and the estimated damage between 1900 and 2010. The rising trend of technological hazards for the last century was starting to decline in 2000. The drop in the number of people affected occurred two decades earlier than the decline of people killed. Though there is a slight rise of estimated damage by technological disasters since 1980s, any single incident can cause huge economic damages.

Are hazards man-made? Are human beings turning hazards into disasters? Firstly, some hazards are initiated by human beings. They are intentional. For example, civil wars may be initiated by power struggle between groups with political or ideological differences. Wars bring in mass injuries, killings, refugees and diseases. The five year (1998-2003) conflict between the Democratic Republic of Congo (formerly known as Zaire), supported by Angola, Namibia and Zimbabwe, and the rebels backed by Uganda and Rwanda over basic resources such as water, access and control over rich minerals and other resources has caused millions of refugees and deaths. Terrorist attacks, e.g. suicide bombing, flight hijack, sabotages, arson and sniper shooting, may be triggered for political, economic or religious reasons. The 911 attack in New York 2001 killed nearly 3000 people. The 7 July bombing in London in 2005 killed 52 people and injured more than 700 people (BBC, 2005).

Secondly, some hazards are turned into disaster by human beings. They are unintentional. This is primarily due to lack of preparation and incapability of the communities or governments to deal with the consequences of the hazards. These hazards may occur naturally. For example, hurricane Katrina could be another hurricane making landfall in America every year, but the levees built to protect New Orleans were not able to withstand the storm surge of category 4 hurricane. Even though the government in New Orleans had known of the limitation of the levees but did not do enough to strengthen them due to the funding cut. Therefore the storm surge caused by hurricane Katrina broke down the levees in New Orleans on 29th August 2005 and put the town under flood water.

Some hazards are accidently caused by human activities. For instance, oil transport vessel, Exxon Valdez, got aground spilling 37,000 tonnes of oil around Prince William Sound, Alaska, USA in 1989. Nearly 5,000 barrels of oil a day was leaked from the site of deepwater horizon rig which sank on 22 April 2010 after an explosion in the Gulf of Mexico. The Chernobyl accident was caused by human themselves while Fukushima nuclear reactor incident was triggered by natural hazard in Japan 2011. Some people may argue this might be the price we have to pay for our human technological development.

Poor countries are disproportionately affected by disaster consequences (Coppola, 2007). In fact, hazards occurring in the poor developing countries can easily be turned into disasters. Lack of money and resources in hazard prevention normally leave the country ill-prepared for the hazards.

Predicting man-induced hazards is even more difficult than forecasting natural hazards. First, there is no time and place restriction for its occurrence. Manmade hazards, e.g. terrorist attack, can occur at any time and in any location. Second, there is hardly a trend or seasonality effect in the pattern of their occurrences. They are sporadic and spottiness in pattern. Third, manmade hazards can happen in different and new forms each time they occur. There may be less similarity between each event. Fourth, our knowledge of the motives and causes of manmade hazards is very limited and thus less preparation has been done primarily to deal with the impact of a particular hazard. Fifth, the scale of the impact zones can be regional or global. For example, the impact by biohazard or cyber attack can cover a large unrestricted area and the area may change dynamically following the movement of people and their activities.

2.3 Hazards and Climate Change

There is a general belief among the media and the public that more natural hazards will be triggered as a result of global warming. However, it is still a scientific question without reaching consensus regarding the linear relationship between natural hazards and climate change. It is believed that (e.g. Webster et al., 2005) the intensity but not the frequency of tropical cyclones might be enhanced in a warmer world. It is known that volcanic eruption can change climate temporarily (Wolfe, 2000) and research are called upon studying the effect of climate change on triggering volcanic activities (e.g. McGuire, 2009). On the other hand, there is no correlation at all between the frequency of earthquakes or tsunamis and climate change. It is illogical to link the number of man-induced hazards, e.g. oil depot explosion, terrorist attack with climate change.

Evidently, the fluctuations in the occurrence frequency of natural hazards may be related to climate variability. For example, the active (inactive) typhoon activities over the Western North Pacific Ocean are due to La Nina (El Nino) phenomena (e.g. Chan, 2000). Indian summer monsoon rainfall peaks (lulls) are caused by Indian Ocean Dipole (Kripalani and Kumar, 2004). Increased chance of droughts in northern China and flood in Yangtze River Valley is due to the fact that the summer (July-August) tropospheric cooling around 300hPa and the southward shifting of upper-level westerly jet stream over East Asia weaken the summer monsoon (Yu et al., 2004).

Nonetheless, it has to be careful in the interpretation of any disaster trend diagram. First, hazard data, particularly those in the past, are patchy and incomplete. Some data were lost in fire and war. Second, the auditing of hazard data can be fuzzy and overlapping. It is never easy to clear cut a hazard from another happening at the same time affecting the same groups of people. For example, do we count a flood after a cyclone as two individual hazards or just one hazard? Whether a drought affecting several neighbouring countries is regarded as a single hazard or several hazards? Whether the famine after a drought affecting the same groups of people is regarded as a single hazard? Furthermore, the definitions of risk, vulnerability, hazard and disaster have been changing throughout history, so data auditing might be inconsistent. Third, the reportage of hazards may be driven by how dramatic the events are (e.g. the Japan disaster 2011) or how helpless the situation is after the hazards (e.g. Haiti earthquake 2010). Besides it may be biased for a western perspective. For example, the cyclone Yasi hitting Australia in 2011 was reported in detail on TV in the UK, probably due to the fact that a lot of English people have relatives there and it is also a popular holiday location for the British.

3. Risk

Risk is the probability of occurrences and losses accrued to human lives and environment by hazards. In other words, risk is the product of hazards and vulnerability.

Risk can be divided into pure risk and speculative risk. Risk can also be classified into systematic and unsystematic risk (Table 3). Risk can be voluntary or involuntary.

Risk management includes identification, estimation and evaluation. Risk identification techniques include brainstorming, hazard and operability studies (HAZOP), failure modes and effects criticality analysis (FMECA), event tree analysis, hierarchical holographic modelling, decision analysis, accident investigation and fault tree analysis.

The next step is to estimate the probability or likelihood (occurrence, frequency and intensity) of hazards and the vulnerability index of (or consequences to) people, property and infrastructure. However, the problems inherited with accurate risk estimation are the availability of reliable data, expression of estimated risk, no scientific objectivity and complexity due to individual risk perception.

Risk can then be evaluated by various methods, e.g. risk matrix, SMAUG methodology (seriousness, manageability, acceptability, urgency, growth) (Tregoe and Kepner, 1981), the "ALARP" principle (as low as reasonably practicable), market mechanism and cost-benefit analysis.

3.1 Risk Modelling and Assessment

Risk assessment is never straightforward. Risk is divided into perceived risk and actual risk. There are always discrepancies in risk perception between the public and those logically calculated from the objective evaluation models. How much risk people can accept depends on how much losses people think they can avoid, absorb and tolerate, the types of hazard, their trust in the capability of the authority in handling disaster, personal experience and media's portray. These may be solely dictated by their personal factors but not by logical conclusion.

Modelling of risk

Deterministic approach has been used to explain the physical mechanisms behind the occurrence and development of natural hazards while stochastic approach is widely used in risk modelling. To quantify risk, recurrence interval and probability of the events are generally used. However, recurrence interval can only be used as an indicator. It cannot tell us with certainty when another event with similar magnitude or scale will happen again. The nature is so unpredictable. Statistical modelling of risk focuses on the probability of the event occurrence. In other words, hence, risk modelling is to calculate this *chance factor* and measure the uncertainty or estimate its reliability. Uncertainties in the model may be inherited from model topology, coefficient of parameters, quality (reliability and availability) of data, model scope, optimization techniques, human subjectivity, and the complexity of the natural environment and human interaction.

There are several reasons why risk is difficult to define.

1) Risk changes continuously in accordance to uncertain situational changes.
2) Risk is hard to represent. It is abstract and not easy to express.
3) There is no universally accepted definition of risk. Risk perceptions (tolerability and the acceptance) are different amongst different people.

So risk is defined here as:

$$R = \sum \left(H_{p1} x H_{p2}\right)\left(V_p x V_\alpha\right) \tag{1}$$

where H_{p1} is the probability obtained purely from the past hazards (e.g. recurrence interval, frequency, intensity, duration, movement). They are fixed.

H_{p2} is the probability of the current hazard based on the current dynamical state of the environment (e.g. the current environmental conditions for the occurrence and triggering mechanisms). They are variable.

V_p is the perceived vulnerability which depends on personal factors (e.g. age, gender), knowledge (e.g. education, experience), personality, attitude and behaviour of the people.

V_α is the actual vulnerability which depends on political (e.g. political regime, willingness of the government on disaster management), economic (e.g. wealth of the country and its people), social (e.g. cultural), physical (e.g. number of floors, building materials and design, size of the building, time of occupancy, value of contents) and environmental (e.g. proximity to hazard location) conditions.

R index should lie between 1 (the highest risk) and 0 (the lowest risk).

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Biographical Sketch

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