Global evaluation of human risk and vulnerability to natural hazards

Hy Dao[1], Pascal Peduzzi[2]

Summary

This paper describes some methodological aspects of the development of the Disaster Risk Index (DRI), a central component of the Reducing Disaster Risk report from the United Nation Development Programme (UNDP/BCPR 2004).

The DRI aims to improve understanding of the relationship between development and disaster risk at the global level. The major assumption behind the index is that differences of risk levels faced by countries with similar exposures to natural hazards are explained by socio-economic factors, i.e. by the population vulnerability. The DRI allows the measurement and the comparison of relative levels of risk, exposure to hazard and vulnerability on a country by country basis. The DRI is also a contribution to a more quantitative evidence for planning and decision making in the field of risk reduction and management.

This paper focuses on the evaluation of risk for four hazards (cyclones, droughts, earthquakes and floods). Starting from data on exposed population, as estimated using Geographical Information System (GIS), a statistical analysis was carried out to identify the socio-economical indicators reflecting human vulnerability to hazards. To calibrate the risk model, past casualties recorded by the database EM-DAT from the Centre of Research on Epidemiology of Disasters (CRED)[3] were used. The final outputs include a set of indicators for measuring levels of risk on a country by country basis, a global database on hazard frequencies, an evaluation of the population exposed and the identification of socio-economical parameters for estimating human vulnerability to natural hazards.

---

[1] University of Geneva, Geography Department & UNEP/DEWA/GRID-Geneva

[2] UNEP/DEWA/GRID-Geneva

[3] Centre of research on Epidemiology of Disasters (CRED), EM-DAT: The OFDA/CRED International Disaster Database, Université Catholique de Louvain, Brussels, Belgium, http://www.em-dat.net/

1. Introduction

Being primarily caused by natural factors or induced by human activities, natural disasters have strong impacts on societies. If economic losses reported by insurance companies are mainly located in developed countries, other impacts on lives and livelihoods are a major concern for developing countries which account for 85% of the people affected by natural hazards.

The “Reducing disaster risk” report, published in 2004 by the United Nations Development Programme (UNDP/BCPR 2004), presents the links between natural disasters and development. The general aim behind this report is to better anticipate, manage and reduce disaster risk, as well as to introduce risk dimensions into planning processes. The report introduces a new index called the Disaster Risk Index (DRI) that will help planners and decision-makers with a quantitative approach of vulnerability and risk to natural hazards, on a country by country basis.

The objective of the article is to present some methodological aspects of the development of the DRI, in particular a statistical model for identifying factors leading to risk of death from natural hazards.

2. Framework of the study

2.1 Defining risk

Following a definition by United Nations, risk “refers to the expected losses from a particular hazard to a specified element at risk in a particular future time period. Losses may be estimated in terms of human lives, or buildings destroyed or in financial terms” (UNDRO 1979; Burton et al. 1993, 34). In the context of human development, loss of livelihood should also be taken into account, livelihood being defined as “the command an individual, family or other group has over an income and/or bundles of resources that can be used or exchanged to satisfy its needs” (Blaikie et al., 1996). However, livelihood is a very complex notion for which little data is available at the global scale.

If the risk represents the losses, ”the hazard can be defined as a potential threat to humans and their welfare” (Smith 1996). Type of threats can be broadly separated into categories such as human made hazards (conflicts, technical accidents,...) and natural hazards resulting from climatic, tectonic or biologic causes (floods, droughts, earthquakes, epidemics, …). Hazards are extreme events that may create risk and potentially turn into disasters if the exposed elements are vulnerable.

2.2 The choice of risk indicators

In the context of this study, the choice of a risk indicator was to a large extent determined by the data availability. EM-DAT is the only publicly available global database on human impacts from hazards. To base the DRI on economical reported losses was not an option because of differences in real purchasing value and high currency rate fluctuation over time, not mentioning the quality and the scarcity of such information. Other possible options were to use information on the number of killed, injured, homeless or affected population. The figures of killed people were chosen because they are probably less subject to variations between countries and cultures. Counting killed people is less dependent on subjective evaluations as well as on differences in reporting infrastructures such as health systems.

However, an other problem arises when comparing countries: if the total number of killed people is taken, populated countries (China, India, etc.) will always be on the top of list of the areas at risk. On the contrary, considering the percentage of population killed will generally give a higher rank to small islands and low populated countries. In the DRI, both figures were considered: percentages of killed people represent the relative risk faced by each country whereas figures on total killed highlight countries and governments facing massive impacts to manage and to recover from.

2.3 The choice of a time period

The period of time for calculating the DRI was 1980-2000. Figure 1 depicts the number of events recorded by EM-DAT for each year since 1950.

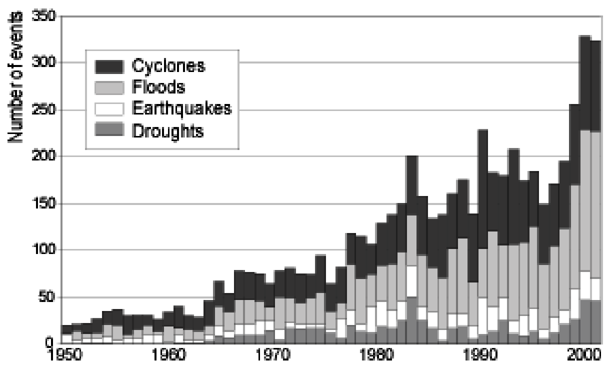

Figure 1
Events (cyclones, drought, earthquakes, floods) reported in EM-DAT (1950-2000)

Hy Dao, Pascal Peduzzi, "Global evaluation of human risk and vulnerability to natural hazards", Enviro-info 2004, Sh@ring, Editions du Tricorne, Genève, isbn 282930275-3, vol. I, p.435-446.

Although the increase in the frequency of hazardous events might be induced by climate change or by increasing densities of population, it mostly results from a significant improvement in the access to information on disasters world-wide. The period 1980-2000 was considered to show a stable access to information, while maximising the length of time for an optimum representation of the hazard periodicity.

2.4 The choice of hazard types

A first analysis on the amount of casualties according to EM-DAT revealed that droughts, earthquakes, cyclones and floods were responsible for about 94% of the total casualties (epidemics excluded), whereas volcanoes, extreme temperatures, landslides, tidal wave and wildfire were accounting for the remaining part.

Given the significance of these four major hazards, modelling others would not have a significant effect on the final classification of countries, except for some selected countries affected mostly by tidal waves, landslides or volcanic eruptions.

EM-DAT considers the original cause of the events; therefore, a landslide following a cyclone is classified as cyclone. This probably explains why these four hazards represent such a majority of the casualties. By drought, one should understand food insecurity induced by physical drought, although in some areas, political insecurity is more responsible for the crisis than climatic factors.

3. Modelling risk

3.1 A general formula

After the UNDRO definition (UNDRO 1979), the risk of losses results from three components: hazard occurrence, elements at risk and vulnerability. In the case of risk of death, the elements at risk are the exposed population. The hazard occurrence refers to the frequency of returning period at a given magnitude, whereas the vulnerability is “the degree of loss to each element should a hazard of a given severity occur” (Coburn et al. 1991, 49).

A hypothesis was made that risk follows a multiplicative function (formula 1).

$$R = H_{fr} \cdot Pop \cdot Vul \qquad (1)$$

Where:

R = number of expected human impacts [killed/year].

H_{fr} = frequency of a given hazard [event/year]

Pop = population living in a given exposed area [population affected/event].

Vul = vulnerability depending on socio-economic factors [no units].

In this formula, risk is measured as the average risk of death per year and per country in large- and medium-scale disasters, based on data from 1980 to 2000. If the hazard frequency or the population vulnerability increases, then risk will be augmented accordingly.

3.2 Identifying physical exposure

In the DRI, the combination of hazard frequency of hazard and exposed population is called physical exposure. This is the average number of people exposed to a hazard type by year. Formula 1 for risk can be simplified as follows (formula 2):

$$R = PhExp \cdot Vul \qquad (2)$$

Where:
R = risk of human losses
Vul = population vulnerability
PhExp = average number of people exposed to a hazard type by year

The extent and frequency of events for each hazard type were mapped using Geographical Systems and spatial models. This information was then combined with the Gridded Population of the World (GPW)[4] for extracting the average exposed population by year (physical exposure). A more complete description of the methodology used for estimating the physical exposure can be found in the technical annex of the Reducing Disaster Risk report (UNDP/BCPR 2004).

3.3 Approaching human vulnerability

3.3.1 A vulnerability proxy from past events

Past (or manifest) risk can be obtained from the EM-DAT reported losses for 1980-2000. From formula 2, a vulnerability proxy is calculated by dividing past risk by the physical exposure (formula 3):

$$Vul = Risk / PhExp \qquad (3)$$

This vulnerability proxy is the average number of deaths per exposed people.

[4] http://sedac.ciesin.columbia.edu/plue/gpw/

Hy Dao, Pascal Peduzzi, "Global evaluation of human risk and vulnerability to natural hazards", Enviro-info 2004, Sh@ring, Editions du Tricorne, Genève, isbn 282930275-3, vol. I, p.435-446.

3.3.2 A parametric model of risk

More interestingly, socio-economic, cultural and political factors explaining the observed vulnerability can be identified by means of a statistical analysis. The multiplicative formula 2 is generalised with a parametric model (formula 4):

$$K = C \cdot (PhExp)^{\alpha} \cdot V_1^{\alpha_1} \cdot V_2^{\alpha_2} \ldots \cdot V_p^{\alpha_p} \quad (4)$$

Where:
K is the number of persons killed by a certain hazard (as reported in EM-DAT).
C is a multiplicative constant.
PhExp is the physical exposure.
V_i are the socio-economical variables.
α_i are the exponents of V_i (which can be negative).

Taking the logarithms in formula 4 gives:

$$\ln(K) = \ln(C) + \alpha \ln(PhExp) + \alpha_1 \ln(V_1) + \alpha_2 \ln(V_2) + \ldots + \alpha_p \ln(V_p)$$

For variables expressed as percentages, a transformation was applied in order that all variables range between -∞ and +∞:

$$V_i' = \frac{V_i}{(1 - V_i)}$$

Where:
V_i' is the transformed variable (ranging from -∞ to +∞).
V_i is the socio-economic variable (ranging from 0 to 1).

Significant socio-economical variables Vi and exponents α_i were determined for each hazard type by the use of linear regressions. In this model, physical exposure is also seen as a potential explanatory variable.

A set of 38 variables on economical features, dependency on the environment quality, demography, health and sanitation, politic, infrastructure, early warning and capacity of response, education and development was analysed. These variables were obtained from various global environment and development reports[5]. A major concern when selecting candidate variables was to minimise the number of country with missing values for keeping a valid sample size.

[5] In particular the Global Environment Outlook http:/geodata.grid.unep.ch and the Human Development Report http://hdr.undp.org/

4. Global risk and vulnerability patterns

4.1 Cyclones

Up to 119 millions of people in 84 countries are exposed each year to cyclone hazards, with a total death toll of 251,000 world-wide for the period 1980-2000.

The variables highlighted by the statistical analysis are the physical exposure, the Human Development Index and the percentage of arable land. The model is the following:

$$\ln(K) = 0.63\ln(PhExp) + 0.66\ln(Pal') - 2.03\ln(HDI') - 15.86$$

Where:
K is the number of killed
PhExp is the physical exposure to cyclones
Pal' is the transformed value of percentage of arable land
HDI' is the transformed value of the Human Development Index

A considerable part of variance is explained by the model (adjusted $R^2 = 0.85$), with a high degree of confidence in the selected variables (p-values$<10^{-3}$) over a sample of 33 countries (see graph of observed versus modelled values in

Figure 2). It must be noted that, due to the exceptional intensities of Mitch and other hurricanes, risks for Honduras and Nicaragua were strongly underestimated; these two countries were therefore not included in the model.

According to the analysis, the number of killed people is positively correlated with physical exposure but negatively with HDI. As the percentage of arable land is probably an indirect way of measuring the dependency of a population on agriculture, analysis shows that a stronger dependence to agriculture induces a higher vulnerability. Although already mentioned by experts, this is now confirmed by statistical evidences. After a cyclone, an economy relying on tertiary sector is less affected than one relying on agriculture, fields being devastated. These results depict that less developed countries are more vulnerable to cyclones.

4.2 Droughts

From the geo-spatial modeling it was found that 130 millions people were exposed to drought hazard every year, causing a total of 832'000 deaths during the period 1980-2000.

The variables selected by the statistical analysis for droughts are the physical exposure and the percentage of population having access to improved water supply:

$$\ln(K) = 1.26\ln(PhExp) - 7.58\ln(WATSUP) + 14.4$$

where:
WATSUP is the percentage of population having access to improved water supply

According to the analysis, the number of killed people grows with increasing physical exposure and decreasing access to water. This latter variable should be seen as an indicator of the level of development of the country as it is also correlated to other development variables (such as HDI). The adjusted R^2 is 0.78, with a p-value of 10^{-3} (see also

Figure 2)

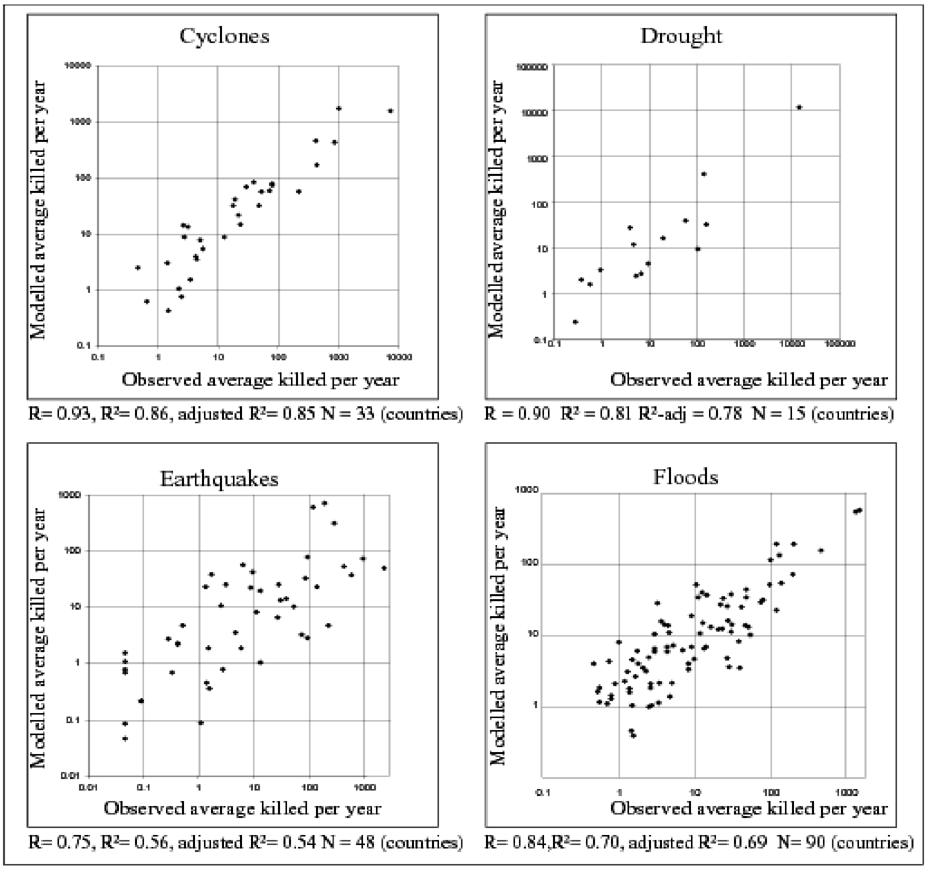

Figure 2
Regression between observed and modelled casualties (log / log scale)