# Global evaluation of human risk and vulnerability to natural hazards

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**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.

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# 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.

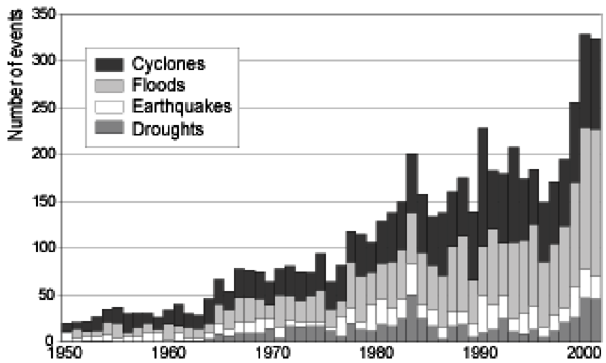


Figure 1
Events (cyclones, drought, earthquakes, floods) reported in EM-DAT (1950-2000)

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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/

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### 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.*
*$\alpha_i$ 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 $\alpha_i$ 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)

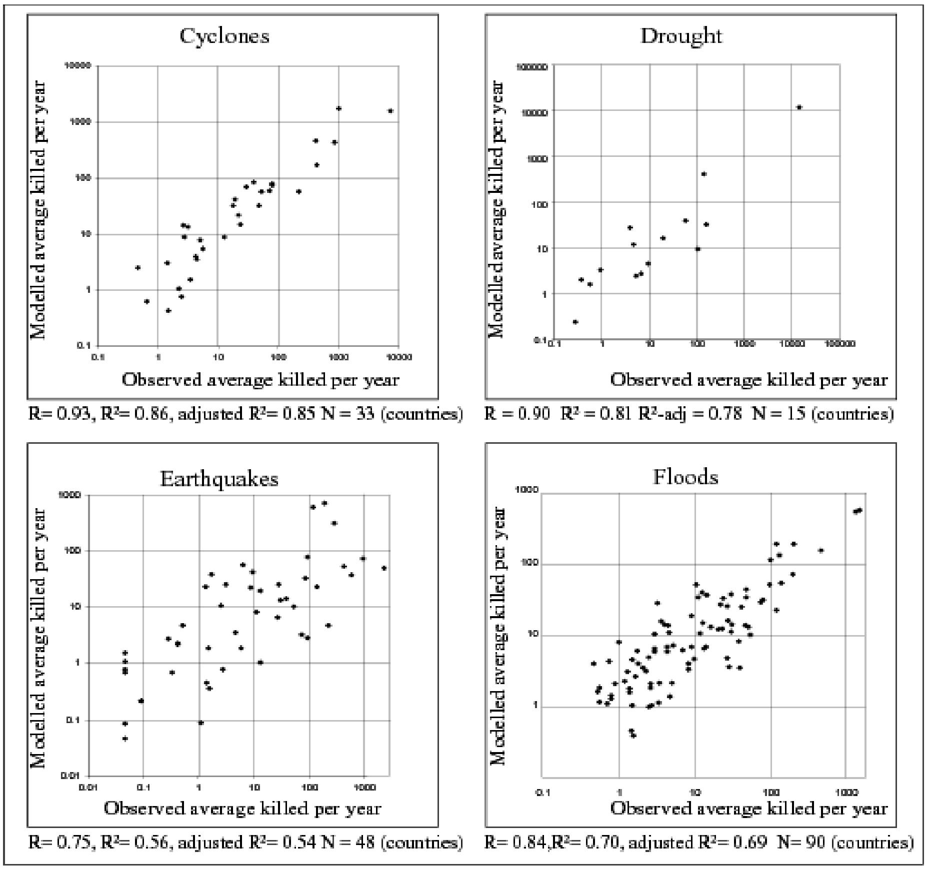


Figure 2
Regression between observed and modelled casualties (log / log scale)

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The outlying values of Mozambique and Sudan were removed from the model. In these cases, droughts might be in fact complex hazards where the physical droughts did not play a significant role and where food insecurity was caused by conflicts.

Due to the difficulty of defining and mapping drought hazards, as well as to the high sensitivity of the model, the case of drought must be considered as work in progress.

## 4.3 Earthquakes

130 millions people per year were exposed to earthquakes, with a total of 159'000 killed between 1980-2000.

Regression analysis shows that urban growth together with physical exposure are statistically associated with the risk of death to earthquake.

$$\ln(K) = 1.26\ln(PhExp) + 12{,}27 \cdot U_g - 16.22$$

where:

*$U_g$ is the percentage of urban growth (computed using a three-year moving average)*

The part of explained variance is smaller than for flood or cyclones (adjusted $R^2$ is 0.54); however considering the small length of time taken into account (21 years as compared to earthquakes long return period), the analysis delineates a reasonably good relation (Figure 2).

In the case of earthquakes, urban growth does not explain vulnerability per se. Levels of risk are rather influenced by the factors linked with rapid urban changes, like poor building quality.

## 4.4 Floods

About 196 millions people in 90 countries were exposed every year to floods with a total of 170'000 deaths for the period 1980-2000.

The variables selected by the statistical analysis are physical exposure, gross domestic product per capita and local density of population:

$$\ln(K) = 0.78\ln(PhExp) - 0.45\ln(GDP_{cap}) - 0.15\ln(D) - 5.22$$

Where:

*GDPcap is the normalised Gross Domestic Product per capita (purchasing power parity)*

*D is the local population density (i.e. the population affected divided by the area affected)*

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The adjusted $R^2$ is 0.69, associated with a significant p-value on 90 countries. As for droughts, the difficulty of mapping of flood hazards at the global scale may explain the relative weakness of the model.

Without surprise, the regression shows that highly exposed and poorer populations are more subject to suffer casualties from floods. More surprisingly, it shows that countries with low population densities (in exposed areas) are more vulnerable than countries with high population densities. It might be due to higher level of organisation in denser areas but this has to be confirmed in future research.

# 5. Comments and perspectives

## 5.1 Scope of the DRI

This research has two main results : the calculation of the average risk of death per country in four types of medium- and large-scale natural disasters between 1980-2000, as well as the identification of associated causal factors. The DRI must be seen as a set of indicators that point out the countries which are most at risk, vulnerable and exposed to floods, earthquakes, cyclones and droughts. An other important feature of the DRI is that it is based on the best available global datasets. All these characteristics define the strengths and the limits of the DRI.

## 5.2 Quality of the model

The method used in this statistical analysis proved to be appropriate and the correlations found between the figures observed from EM-DAT and those from the models were higher than expected. The sign of the exponents in the models follows what the common sense and specialists would have recommended with the notable exception of local density for flood. Except for drought, physical exposure appeared to be the most significant factor leading to risk. In a sense this validates also the methodology developed for estimating the number of people exposed to natural hazards. In the case of drought, the socio-economical context plays a stronger role.

The research has highlighted a relation between higher level of development and low casualties from four types of hazards. Stating that there is a relation can be understood both ways: lower development may lead to higher casualties, but high hazard occurrence may also lead to lower economical development as it destroys infrastructures and crops as well as scares the investors away.

However, **such models should not be used as a predictive models**. Firstly because the precision of data sources is not sufficient. Secondly, because significant discrepancies of losses between two events in the same country can be found, highlighting the local variability due to specific conditions in each individual hazard. Finally, extraordinary events, like hurricane Mitch, are by definition very difficult to model.

## 5.3 Recommendations

From the lessons learned during this research, a number of recommendations can be made for future research:

- Improve socio-economic variables, in terms of precision and completeness. For instance, data on conflicts and corruption would have been very interesting to be tested.
- Improve data on exposure, in particular for floods and droughts. For floods, the exposed areas were overestimated because entire watersheds were considered as flooded areas.
- Conduct a specific study for small countries, in particular for small islands and archipelagos. In these cases, physical exposure for each individual island is difficult to map and socio-economic variables are often missing. Furthermore, the vulnerability of small countries might be caused by other factors than for bigger countries.
- Extend the modelling to other hazards like volcanic eruptions, tsunamis, landslides, epidemics and conflicts. In some countries these threats are a major concern and may interact with other hazards.
- Consider other risk indicators such as economic losses, loss of livelihood.
- Propose a method for evaluating multiple hazard impacts. One way would be to calculate a multiple risk by summing the number of killed people of all hazards. But combined hazards may have a multiplicative effect rather than an additive one. Furthermore, exposure and vulnerability to different hazards cannot be compared by simple additions.
- Include indicators on disaster risk management and reduction. In the present research, DRI only measures the levels of risk and their associated factors, but not the actions taken to reduce risk.
- Propose a summary index for classifying countries according to their risk levels. This summary index may consist in a combination of percentages and/or totals of loss.

## 5.4 Last word

The risk maps provided in this research are not to be confused with danger maps. At a local scale predictive models can and should be made for better urban planning and improved evaluation of risk. Maps at global scale have the only aim of identifying the countries with the highest patterns of risk, hence the higher needs for disaster reduction measures to be supported by international organisations.

This research underlines the usefulness of continuing the improvement of data collection for a better identification of populations at risk. However, constructing an risk index is not a final result per se. The ultimate objectives will be only fulfilled when proper risk reduction measures are implemented, leading to an observed decrease of casualties.

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