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برنامج الأمم المتحدة للبيئة • 联合国环境规划署
PROGRAMME DES NATIONS UNIES POUR L'ENVIRONNEMENT • PROGRAMA DE LAS NACIONES UNIDAS PARA EL MEDIO AMBIENTE
ПРОГРАММА ОРГАНИЗАЦИИ ОБЪЕДИНЕННЫХ НАЦИЙ ПО ОКРУЖАЮЩЕЙ СРЕДЕ

Insight on common/key indicators for Global Vulnerability Mapping

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1. Introduction

With growing infrastructures complexity, the world population is facing increasing environmental risks such as water, air and soil contamination due to organic, chemical or nuclear wastes and accidents. Human activities pressures natural habitat through agriculture's practices and forest fires, leading to biodiversity losses. The vegetation removal increases the risks of extended floods and soil erosion occurrence. Adding to these human induced threats, natural hazards such as volcanic eruptions, cyclones, floods and earthquakes are causing more and more victims due to higher population densities.

In 12 months, Webrrelief has reported 29 floods, 10 major earthquakes, 9 Droughts, 6 hurricanes, 3 mudslides and landslides. So far the international community has mainly reacted after the events. Financial support was principally provided for aid and mitigation. There is a crucial need for developing a culture of prevention including landscape management and urban planning, education and early warning systems.

In order to prioritise the populations that are facing higher threats, maps showing risks could be a useful tool for decision makers. Whereas for a selected hazard mapping is easy to achieve at a local scale, the question is much more complex and controversial, if we speak of multiple hazards at a global scale. Some elements of discussion and approaches will be discussed in this presentation.

2. Definitions

Before developing any further it is essential to provide clear definitions on how the terms "early warning"[1], "vulnerability" and "risk" are used here. The conception of vulnerability can change considerably depending on the view, the object taken into account and the end users or the background of decisions makers. In this presentation the following terms should be taken in the sense as described in Table 1.

Table 1. Definitions

Early warning:

A process that provides timely information so that communities are not only informed, but sufficiently impressed, that they take preparedness actions before and during the anticipated hazardous event. Sources: IDNDR

Risk*:

A measure of the expected losses due to hazard event of a particular magnitude occurring in a given area over a specific time period. Sources: Tobin & Burrel (1997)

Vulnerability*:

The degree of loss to each element should a hazard of a given severity occur. (Coburn et al. 1991, p. 49).

A general acceptation of the formulation for risk estimation can be described by the following equation:

$$\text{Risk} = \text{Frequency} \times \text{Population} \times \text{Vulnerability}$$

Where:

Risk = *Number of expected human losses per exposed population per time period (e.g. per year)*
Frequency = *Expected (or average) number of events per time period*
Population = *Number of exposed population*
Vulnerability = *Expected percentage of population loss due to socio-politico-economical context*

If the probability of occurrence is null, then the risk is null even if the population is dense and poor; in the same way if the frequency is high but the area is desert, the risk is null. In this study, vulnerability should be taken in the sense of population vulnerability and not for costly infrastructures. This is a subjective choice

[1] *A process that provides timely information so that communities are not only informed, but sufficiently impressed, that they take preparedness actions before and during the anticipated hazardous event.* Sources: IDNDR

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but need to be specified in order to avoid confusions. The vulnerability or risk of losses as computed by banks or insurance companies may sensibly differ.

In the formula, the probability of hazard occurrence can be estimated in two ways:

1) By scientific computation or modelling of the process. This requests a significant amount of data, local measures and scientific research.
2) By statistics, based on past observations. This needs a comprehensive database in order to derive probability.

The vulnerability depends on three main components: the enhancing physical factors (see Table 2 for details), the socio-economical factors (population density, quality of infrastructures, collectivity organisation) and the response capacity (prevention, early warning system, capacity of aid and interventions, mitigation).

3. Hazards characteristics

Natural hazards have always occurred, however what has changed is the higher density of human infrastructures and settlements. Earthquakes may have always existed, this is not the case of nuclear power plants. Now if an earthquake occurred at a location containing such infrastructure the effect on the population would be different!

The increasing population density has also force people to live in places that were not used before, such as slopes, areas with risk of floods, unstable soils that are now used because of lack of other surface, especially around large cities. The Table 2 shows the enhancing factors that could cause a natural event to become a disaster.

Table 2. Enhancing Factors

		Contextual Factors Enhancing Vulnerability															
		Climatic				Physical				Bio/Geo			Socio/economical				
	Types of Hazards	Precipitation	Atm. pressures	Temperatures	wind	Elevation	Slopes	Rocks/Soils	Hydrology	Vegetation Types	Distance to sea	Latitude	Economical activ.	Pop. Density	Infrastructures	Accessibility	Political system
Tectonic	Earthquakes							●					●	●	●	●	●
	Tsunamis					●					●		●	●	●	●	●
	Volcanoes	●					●						●	●	●	●	●
	Landslides	●					●	●	●				●	●	●	●	●
Climatic	Floods	●				●	●	●	●	●			●	●	●	●	●
	Droughts	●		●			●	●	●	●			●	●	●	●	●
	Tropical Cyclones		●	●		●	●		●			●	●	●	●	●	●
Human induced	Global warming	●	●	●	●					●	●	●	●	●	●		●
	Forest Fires	●		●	●					●			●	●	●	●	●
	Erosion	●					●	●	●	●			●	●	●	●	●
	Air pollution	●			●	●							●	●	●	●	●
	Soil pollution	●					●	●	●				●	●	●	●	●
	Water Pollution						●	●	●				●	●	●	●	●
	Ozone depletion			●	●							●	●	●	●	●	●
	Pest invasion	●		●		●	●	●	●	●			●	●	●	●	●
Bio	Diseases			●		●							●	●	●	●	●

This table delineates the multiplicity of vulnerabilities. A population located in an area sensitive for volcanoes may not be as exposed to floods.

There is a need to separate the physical causes leading to the occurrence of the event, from the enhancing factors causing this event to degenerate into a disaster.

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To illustrate with a more concrete situation, the case of tropical cyclones can be considered. The causes are both climatic and physic: a sea temperature higher than 26°C, combined with a low atmospheric pressure as well as high Coriolis forces from earth's rotation. The exposed population (or population at risk) are located on inter-tropical areas (but not at the equator where the Coriolis force is null), close to ocean (less than 100 Km) and mostly on east coasts of continent. The vulnerability toward cyclones, may rely on poor infrastructures, bad access, low elevation, precarious access to information, or even with political conflict.

Following our previous formula, the risk of population losses, can be modelled in function of the population living on east coasts of tropical regions, located at less than 100 km from the coasts, with low elevation, poor economy and at the end of summer (when the sea water are at the warmest).

If characteristics of all hazards can be modelled then areas where risk is the highest could be identified. Highlighting the places where the populations are vulnerable and are facing a high probability of hazards occurrence!!! The total risk is then computed with the following formula:

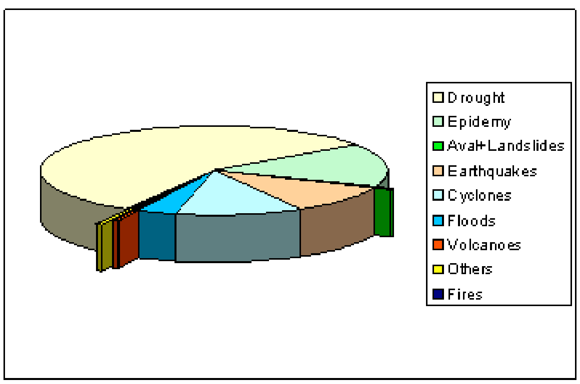
$$Risk_{TOTAL} = \text{Risk from Volcanoes} + \text{Risk from Floods} + \ldots + \text{Risk from N}$$

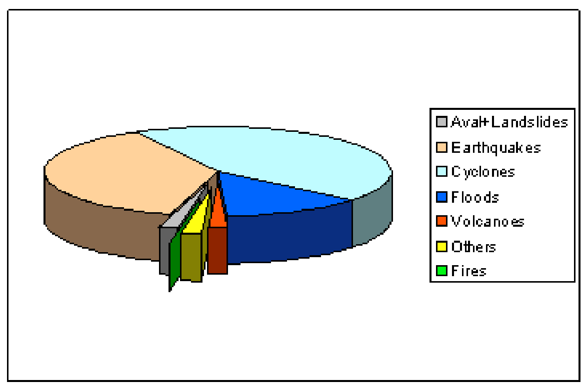
If for some hazards the frequency of occurrence can be reduced (by building dam to contain flood or by stabilising slopes) nothing can be done to decrease cyclone or earthquakes occurrence, however, one may act on vulnerability. Physical factors need to be taken into account when planing human settlements, capacity of response can be developed.

4. Intrinsic problems for global index on risk or on vulnerability

The generation of an index that takes into accounts a global risk or global vulnerability is complex. Several questions need to be solved. First of all, what hazards should be considered? Vulnerability is not the same from one hazard to the next. Depending on the selection made the parameters, weighting and results will differ as shown on Table 3.

Table 3. Which hazards should be taken into account ?



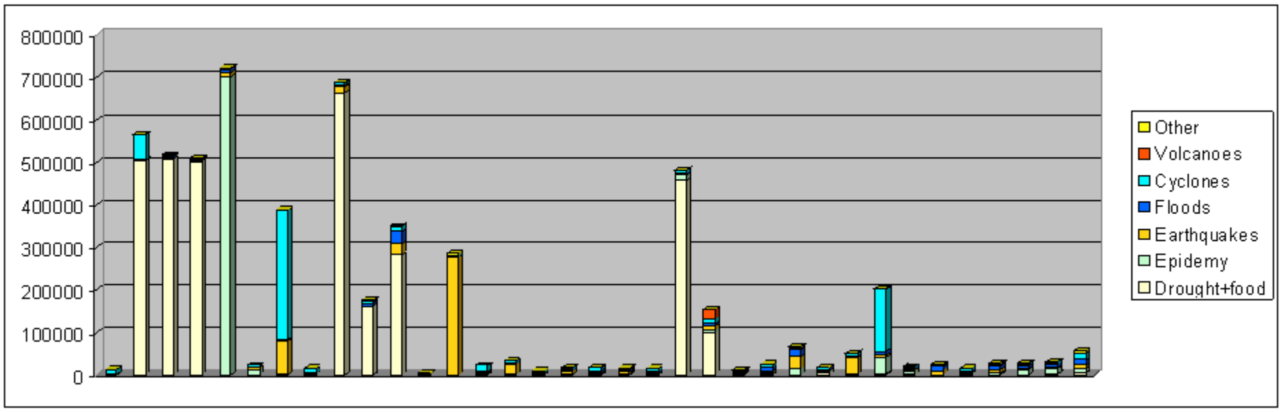


Sources: CRED

If drought and epidemics are included in the index, the number of victims from floods and earthquakes does not change, but seemed minimised in comparison of the two others.

Then the computation of the probability needs either an extended set of data, which are not always available for all places. If computed statistically, what length of time should be taken into account ? This will depends on the availability of the data, however it the length of time considered completely change the computation of the frequency as depicted by Table 4.

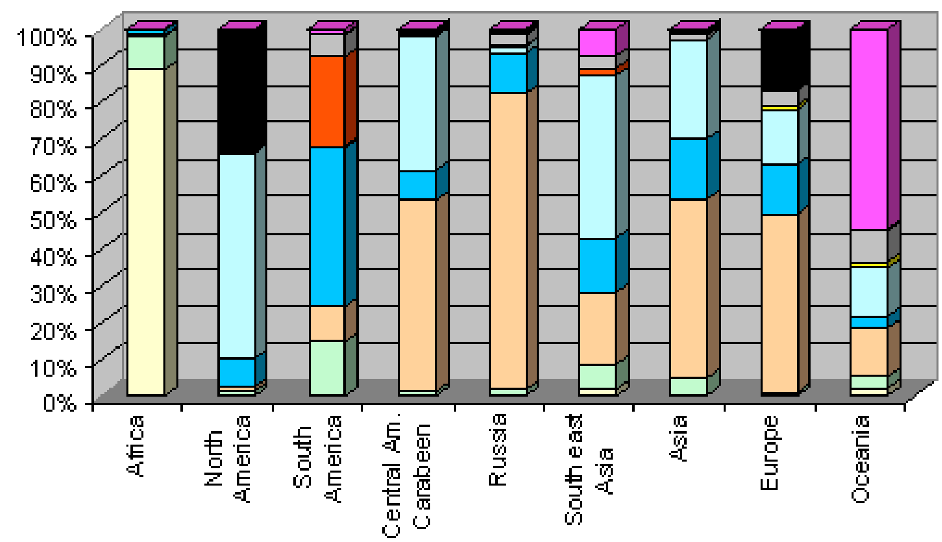
Table 4. Number of victims by type of hazards since 1964



Sources: CRED

On what ground should be based the selection of hazards considered for computing global risk ? Should human induced hazard such as mines, pollution, nuclear wastes and accident be incorporated as well ? The distribution is not the same for each continent as depicted by Table 5 (and even more different considering each country). In fact from one valley to the next, the risk can change.

Table 5. Proportion of victims from hazards by continent



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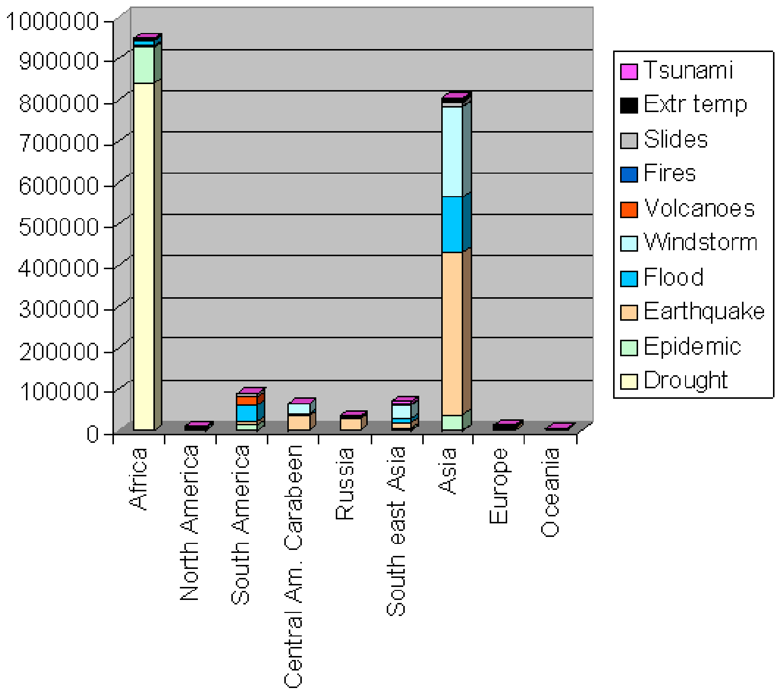
How to compare the situation of earthquakes in South America with the problem of drought in Africa ? Not only the number of people affected is very different as seen on Table 6, but also the percentage of occurrence vary largely for each continent.

Table 6. Number of victims per continent



Hazards impacts differs in:

- Scales: local/regional/global, coverage (punctual/large area)
- Danger: Frequency, magnitude
- Length: short term/long term

Their comparison constitutes a true challenge!

5. The question of indicators

Following the precedent comments, the question of indicators is then quite "tricky" and even seems insoluble. If comprehensive models require data that may not be available world-wide, one should start with what is available at a country scale. The problem can then be taken the other way round. What do we have and how reliable is it?

Simple indices relying on good data and with stated limitation and subjectivity might be much more efficient than complex ones that cannot be computed because of the lack of (reliable) data.

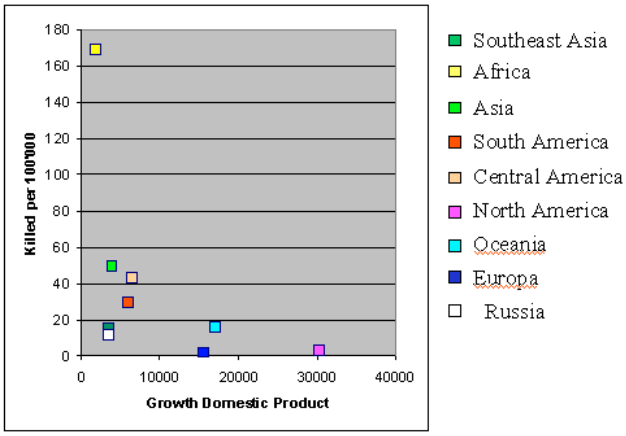
Taking this last philosophy, one can start with an inductive approach. The risk (expected human losses) should be normalised by the quantity of population living in a country (or other given area), so that comparisons can be derived between countries. In the risk there are three components: frequency of hazards, population and vulnerability. The population is the easiest one, the risk will be function of the number of people living in a given area: if nobody is living in a place then the risk is null and the vulnerability irrelevant.

The frequency and severity of hazards may be computed based on historical datasets and modelled by a spatial analysis using a Geographical Information system (GIS) for example. This will request extensive generalisation and a large amount of data, which may not be always available.

The vulnerability may be approached following a more deductive method. Are there intrinsic forcing functions for vulnerability such as quality of accesses, hospitals, solidity of habitat seems important, once again purely on a deductive way. How can we reflect the global quality of infrastructures? The only available figures may rely on the economic development, so Gross Domestic Product (GDP) may be useful to reflect it. Other indicators could be incorporated such as the level of education, the capacity of response to a hazards: but how to incorporate this without specific? And how to weight them in the process?

Once a selection of available indicators is made, a statistical analysis can be undertaken to identify correlation.

Table 7. Number of killed per million in relation with GDP



The scatter plot in Table 7 delineates the relationship between the GDP and the normalised number of victims (victims per 100'000) seems to follow a negative exponential function. The GDP seems to have a great influence on the number of victims but not in a linear way, unless Africa – mostly affected by drought – is an exception.

After a rough exploratory of several combinations of ratio computed and correlated with the database from Centre for research on the Epidemiology of Disasters (CRED), those that present the best correlation with the normalised number of victim (number of victims per 100000) were the following:

Test Vulnerability Index 1 = Density of Population) / (Gross Domestic Product^3)
Correlation with the normalised number of victim is r = 0.66

Test Vulnerability Index 2 = Density of Population) / (Gross Domestic Product^3*HDI)
This demonstrated that the Human Development Index is not adding information r = 0.64.

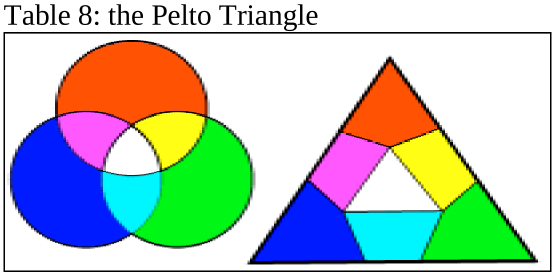
The demonstrated algorithms were tested on 50 countries and correlated with the database from CRED. These vulnerability Indexes do not explain everything (66% for the best one) as the probability of being hit by a natural hazard is not taken into account.

This is a first try, and most probably not be the best indicator: further extensive statistical analysis conducted on all countries should be carried out. However, it shows that a simple index computed with general information can have a significant correlation with factual figures such as the normalised number of victims.

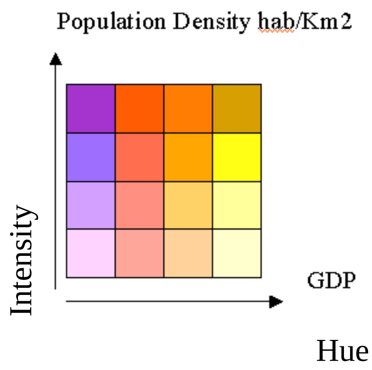
6. Principles for vulnerability mapping

The map showing vulnerability should reflect the probability of an event to occur as well as the vulnerability.

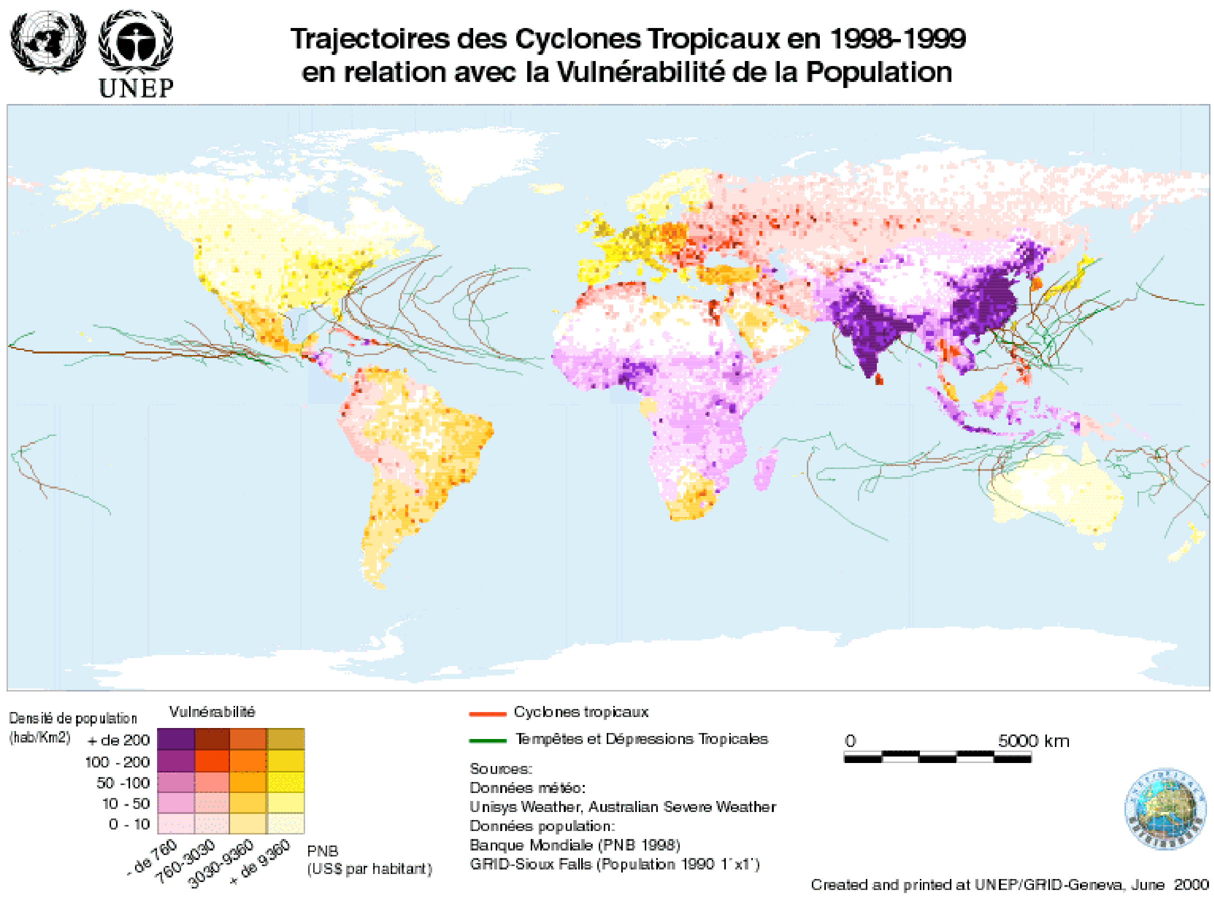
Table 8: the Pelto Triangle



In order to represent multiple variables, there are several solutions:
Computing a ratio (or any index) between the variables. Or displaying all the variables in different channel of colour (three maximum). This method is called the "Pelto Triangle". For two variables a "rectangle of Pelto" can be used.



The map below indicates how Gross Domestic Product and Population Density were represented in one layer.
The density of population varies in colour intensity, whereas the GDP varies from four classes of hue ranging from yellow to purple.
The population density reflects the change of vulnerability within the country. This adds finer information delineating vulnerability at a more local level.



The colours represent both the density of population and the GDP. A country with a high GDP and a low density of population has a low vulnerability (pale yellow). In the opposite a country with a low GDP and a high density of population presents a high vulnerability (dark purple). On top of this layer, one can add the events (here the tropical cyclone for 1998/99) or even better, the probability of an event to occur. This method allows the visualisation of the risk for the population and avoids the problem of weighting the different factors. The only subjectivity of the map lies in the choice of colour (that highlight risk for population and not risk for investments and/or infrastructures) and the choice of the classes for the population. The categories of GDP follow the 4 classes provided by the World Bank.

7. Need to take into account the capacity of response of a country

Can the GDP represent the capacity of response of a country ? This includes prevention (appropriate planning and infrastructures), early warning, aid and mitigation. The economic indicators may provide some of the information, however they will not take into account the level of education for example. The Human Development Index (HDI) may be of some help in this respect.

If the aim of a global vulnerability index is to provoke a reaction in the country concerned, then the effort in capacity of response (prevention, planning, early warning, aid and mitigation) should be targeted. In risk management, the capacity of response is the only variable that a government can change in the short term, the probability of an event to occur being likely to change in the next thousand of years. The vulnerability component, such as the density of population or the GDP will not change rapidly. In this case the only changes that can be achieved in a decade is the improvement in the capacity of responding.

8. Conclusions and propositions to be discussed

What appears in this discussion is that the risk is difficult to calculate, because a significant amount of data may not be available. Furthermore the comparison of different risks is a complex question as the hazards are different in scale, length and danger. The localisation of risks varies from one place to the next. At country level, the integration of the equation will be hard to conduct.

The evaluation of the risk can be approximated by the following formulae:

$$RiskTOT = \Sigma [PopEXP \times H1 \times VH1 + PopEXP \times H2 \times VH2 + \ldots + PopEXP \times Hn \times VHn]$$

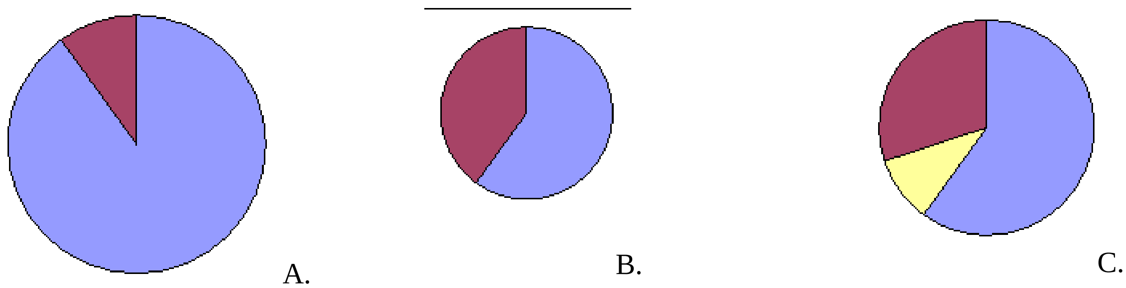
Where:

Pop_{EXP}	= *Population exposed to the hazard*
$H_1 \ldots H_n$	= *Type of Hazard*
$V_{H1} \ldots V_{Hn}$	= *Vulnerability to type of hazard*

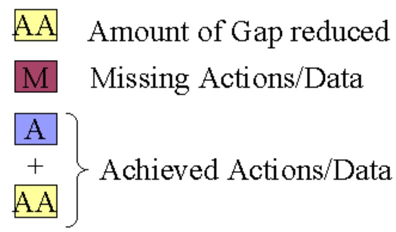
Otherwise general figures such as density of population, Gross Domestic Product (GDP) and Human Development Index (HDI) may offer a general alternative for classifying countries. This can not be used, however, for risk management purpose.

The main difficulty will lie in measuring the capacity of response of the countries. One solution could be an overall evaluation of the total amount of actions needed for a selected country, and then measuring the rate at which this country is filling the gap by an evaluation of the number of actions and measure taken in a year as shown in the following feature. This could reflect the willingness of this government to improve the situation.

Table 9: Amount of actions and information achieved



A. Country with a large amount of actions required but nearly completed.
B. Country with smaller amount of actions requested but not as well completed.
C. In yellow we could evaluate the amount of yearly efforts made by a selected country to reduce the gap and thus its vulnerability.



In the figures of Table 9, the size represents the total amount of actions and information needed to deal with Vulnerability, the colours depict the percentage of complexion achieved and the progress made in one year.

This is just a general idea. It takes into account the amount of data and actions requested (directly connected to the vulnerability), the status of the country (how much has been done up to now) and the speed at which a selected country is bridging the gap. These three components could be statistically plotted and compared in order to classify the countries.

The problem of verifying the information and how to measure these parameters is still not solved and a methodology on how measuring this parameters needs to be elaborated.

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References:

Tobin, G.A. & E.M. Burrel, (1997) *Natural Hazards: explanation and integration*, Guilford Press, London.

Definitions of early warning
IDNDR
http://www.idndr.org/earlywarning.htm

Database on the number of victims per event
CRED
http://www.cred.be/

Statistics on Gross Domestic Product (GDP)
Worldbank
http://www.worldbank.org/

Statistics on Human Development Index
UNDP
http://www.undp.org

Density of population
Digital Chart of the World (1998)

Tracks of tropical cyclones:
Unisys Weather
http://weather.unisys.com/
& Australian Severe Weather
http://australiansevereweather.simplenet.com

Appendix: Statistics for Index calculation using 50 countries

	Country	Killed	POP_CNTRY	SQKM_CNTRY	DENSITY	GDP	HDI	vict/ 100000	Vul Index	Vul Index	Vul Index
									dens pop/gdp*hdi	dens pop/gdp^3	pop/gdp^3*hdi
								r=	0.558	0.662	0.647630615
1	Bangladesh	1070780	120732200	138507	871.67	1331	0.368	886.9	177.96	3.69672027	1.00454E-06
2	Albania	195	3416945	28755	118.83	2788	0.655	5.7	6.51	0.054834496	8.37168E-09
3	Algeria	8327	27459230	2320972	11.83	5442	0.737	30.3	0.29	0.000734079	9.96037E-11
4	Angola	3296	11527260	1252421	9.20	1600	0.335	28.6	1.72	0.022470659	6.70766E-09
5	Argentina	22458	33796870	2781013	12.15	8937	0.884	66.4	0.15	0.000170254	1.92595E-11
6	Australia	1767	17827520	7706142	2.31	19285.000	0.931	9.9	0.01	3.22548E-06	3.46454E-13
7	Belgium	102	10032460	30480	329.15	20985.000	0.932	1.0	1.68	0.000356181	3.82169E-11
8	Benin	658	5175394	116515	44.42	1696.000	0.368	12.7	7.12	0.091051015	2.47421E-08
9	Bolivia	1279	7648315	1090353	7.01	2598.000	0.589	16.7	0.46	0.004000195	6.7915E-10
10	Canada	51917	28402320	9904700	2.87	21459.000	0.960	182.8	0.01	2.90191E-06	3.02282E-13
11	Chad	7243	6308708	1168002.000	5.40	700.000	0.288	114.8	2.68	0.157471774	5.46777E-08
12	China	1191535	1200000000	9338902	128.49	2604.000	0.626	99.3	7.88	0.072771695	1.16249E-08
13	Colombie	32265	34414590	1141962.000	30.14	6107.000	0.848	93.8	0.58	0.001323144	1.56031E-10
14	Congo	277	2318276	345429.500	6.71	2410.000	0.500	11.9	0.56	0.004794624	9.58925E-10
15	Costa Rica	2,149	3319438	51608.039	64.32	5919.000	0.889	64.7	1.22	0.003101717	3.489E-10
16	Ecuador	14698	10541820	256932.000	41.03	4626.000	0.775	139.4	1.14	0.00414458	5.34784E-10
17	Egypt	11700	56133430	982910.375	57.11	3846.000	0.614	20.8	2.42	0.010038754	1.63498E-09
18	El Salvador	6364	5752470	20696.510	277.94	2417.000	0.592	110.6	19.42	0.196846317	3.32511E-08
19	Ethiopia	613362	53142970	1132328.000	46.93	427.000	0.244	1154.2	45.05	6.028231895	2.47059E-06
20	France	914	57757060	546728.875	105.64	20510.000	0.946	1.6	0.54	0.000122444	1.29433E-11
21	Ghana	1754	16698090	239980.906	69.58	1960.000	0.468	10.5	7.59	0.092410622	1.97459E-08
22	Greece	2458	10307460	131851.906	78.17	11265.000	0.923	23.8	0.75	0.000546854	5.92475E-11
23	Guatemala	76375	10321270	109501.797	94.26	3208.000	0.572	740.0	5.14	0.028550178	4.99129E-09
24	Haiti	12765	7044890	27156.939	259.41	896.000	0.338	181.2	85.66	3.606362435	1.06697E-06
25	Honduras	19134	5367067	112852.000	47.56	2050.000	0.575	356.5	4.03	0.055203444	9.6006E-09
26	Hungary	352	10310410	92782.203	111.12	6437.000	0.857	3.4	2.01	0.004166398	4.86161E-10
27	India	9121520	894608700	3089282.000	289.58	1348.000	0.446	1019.6	48.17	1.182240647	2.65076E-07
28	Indonesia	59743	189331200	1910842.000	99.08	3740.000	0.668	31.6	3.97	0.018940115	2.83535E-09
29	Iran, Islam Rep	142852	64193450	1624760.000	39.51	5766.000	0.780	222.5	0.88	0.002060998	2.64231E-10
30	Irak	20	20941720	436421.906	47.99	3159.000	0.531	0.1	2.86	0.015221482	2.86657E-09
31	Ireland	38	5015975	69384.156	72.29	16061.000	0.929	0.8	0.48	0.000174493	1.87829E-11
32	Israel	36	5694890	20773.820	274.14	16023.000	0.913	0.6	1.87	0.000666404	7.29906E-11
33	Italy	116157	57908880	300979.500	192.40	19363.000	0.921	200.6	1.08	0.000265027	2.8776E-11
34	Jamaica	2650	2407607	11043.860	218.00	3816.000	0.736	110.1	7.76	0.039231924	5.33042E-09
35	Japan	217533	125746300	373049.406	337.08	21581.000	0.940	173.0	1.66	0.000335362	3.56768E-11
36	Kenya	3434	25835250	584428.688	44.21	1404.000	0.463	13.3	6.80	0.159727546	3.44984E-08
37	Madagascar	1874	13046690	594856.375	21.93	694.000	0.350	14.4	9.03	0.65616009	1.87474E-07
38	Mali	3926	9744733	1256747.000	7.75	543.000	0.229	40.3	6.24	0.484309065	2.11489E-07
39	Mexico	30404	92380850	1962939.000	47.06	7384.000	0.853	32.9	0.75	0.001168961	1.37041E-10
40	Morocco	13694	27767920	403859.812	68.76	3681.000	0.566	49.3	3.30	0.013785269	2.43556E-09
41	Mozambique	109246	16604660	788628.875	21.06	986.000	0.281	657.9	7.60	0.219647654	7.81664E-08
42	Myanmar	7662	43099620	669820.875	64.34	1051.000	0.457	17.8	13.40	0.554251165	1.2128E-07
43	Nepal	21166	19927280	147292.594	135.29	1137.000	0.347	106.2	34.29	0.920419304	2.65251E-07
44	Netherlands	1855	15447470	35492.691	435.23	19238.000	0.940	12.0	2.41	0.000611278	6.50296E-11
45	New Zealand	445	3528197	266820.188	13.22	16851.000	0.937	12.6	0.08	2.76348E-05	2.94929E-12
46	Nicaragua	16472	4275103	129047.398	33.13	1580.000	0.530	385.3	3.96	0.083989708	1.58471E-08
47	Nigeria	17641	97228750	912038.625	106.61	1351.000	0.393	18.1	20.08	0.432330051	1.10008E-07
48	Pakistan	28696	126693000	877753.375	144.34	2154.000	0.445	22.7	15.06	0.144425212	3.24551E-08
49	Papua New Guinea	3457	4039033	466161.188	8.66	2821	0.525	85.6	0.59	0.003859509	7.35145E-10
50	United States	39970	258833000	9450720.000	27.39	26397	0.942	15.4	0.11	1.48899E-05	1.58067E-12