Evaluación de Riesgos Naturales
- América Latina -
Consultores en Riesgos y Desastres

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CAPRA

CENTRAL AMERICA PROBABILISTIC RISK ASSESSMENT

EVALUACIÓN PROBABILISTA DE RIESGOS EN CENTRO AMÉRICA

BELIZE

TASK III
RISK EVALUATION

TECHNICAL REPORT SUBTASK 3.5
HOLISTIC RISK EVALUATION

CEPREDENAC

Estrategia Internacional
EIRD
para la Reducción de Desastres

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LIMITATIONS AND RESTRICTIONS

This application is illustrative, and has limitations and restrictions due to the level of resolution of available information. The final user should be aware of this, so that he will be able to make appropriate and consistent use of the results obtained, taking account of the type of analysis made, the type and quality of data used, the level of resolution and precision, and the interpretation made. Therefore, the following should be noted:

- Models used in the analysis contain simplifications and suppositions in order to facilitate the calculation which the user of which the user should be aware. They are described in detail in the related technical reports.
- The analyses have been developed with the best information available, within limitations of reliability and currency. It is possible that better and more complete information exists, but that we did not have access to it.
- The information used and the results of the analysis of hazards, exposure and risk are associated with a level of resolution, depending on the unit of analysis used, and this is explained in the descriptive document of the example.
- The use which the final user makes of the information does not in any way involve liability on the part of the authors of the study is made, who present this example as a something which could be feasible, if reliable information with appropriate degrees of precision were made available.
- It is the user´s responsibility to understand the type of model used and its limitations, resolution and the quality of data, limitations and assumptions for analysis, and the interpretation made in order to give these results appropriate and consistent use.
- Neither those who developed the software nor those who promoted and financed the project, nor the contractors or subcontractors who took part in applications or examples of the use of the models, assume any liability for the use which the user gives to the results presented here, and therefore they are free of all liability for loss, damage, or effects which may be derived from the usual interpretation of these demonstrators examples.

Contents

Illustrations index

Table index

1 Purpose of the study

If the causes of risk are to be corrected through the intervention of vulnerabilities, and through strengthening risk management capacity in all its modes and circumstances, then it will be necessary to identify and recognize existing risks and the possibility that new ones will arise, as seen in terms of disasters. This implies that we must dimension or measure the risk and monitor it, in order to determine the effectiveness and efficiency of the means of intervention, which may be corrective or prospective. The evaluation and monitoring of risk is an unavoidable step towards recognition by a range of actors in society, and the decision-making instances responsible for managing it.

In other words, it is necessary to "make the risk manifest", publicise it, and identify its causes. As a consequence, evaluation and follow-up must be effected using appropriate tools to facilitate understanding of the problem, and to guide decision-making.

This document offers a step-by-step description of a method for evaluating risks from hurricane-force winds for Belize, taking an integral and holistic view that includes physical risk, economic and social variables, and the capacity for response in the event of disaster. This method may be used to guide decision-making in risk management, identifying places which may be particularly problematical in the face of a catastrophic event, not only due to physical damage which may arise – or, direct impact - but also due to socioecomomic factors and the lack of resilience which may aggravate the situation, and help to generate what could be considered as an indirect or second-order impact.

When taking account of the spatial level at which work is done when risk evaluations are made on a national scale, there must be information available about potential damage and loss in exposed elements of the country, in each zone (persons, buildings, vital lines, other infrastructure, etc.). The method used in this study identifies a series of circumstances or conditions that would make it more likely that an intense phenomenon would become a disaster, in order to take action in advance, intervene the circumstances and diminish the impact of some future hazardous event. The focus of this evaluation technique, from a holistic point of view, may have an important influence on the effectiveness of risk management, since it facilitates orientation in respect of the measures of mitigation and prevention that should be promoted, depending on the type of result obtained, through indicators which can provide an integral description of risk conditions of the country as a whole. The use of the technique is not limited to the identification of the existence of weaknesses – such as is commonly the case with studies whose only purpose is to evaluate physical risk; it also tries to identify other social aspects which it may be practical to intervene, and which contribute significantly to the risk.

Using the results of the Catastrophe Risk Profile for Belize (Report ERN-CAPRA-T3.3), obtained by this consultancy group in the context of the development of the CAPRA platform, and a series of variables that characterize social aspects and the context of the Districts of Belize, this study had the objective of making a holistic evaluation of the risks of threat from hurricane-force winds, identified as the most important risk for that country. We have only taken account of work of Cardona (2001) and Carreño et al (2004; 2005), for the Inter-American Development Bank (IDB), in which a method for the holistic evaluation of risk on an urban scale has been developed and improved (IDEA, 2005).

This version has used the expected annual loss or pure risk premium as the indicator of physical risk for the case of a hurricane, in respect of public and private buildings, urban and national infrastructure and vital lines. Details of this type of evaluation are to be found in the report ERN-CAPRA-T3.3 (Country Risk Profile, Concentration of Risk and Risk Maps, ERN 2010), where there is an illustration of the calculation of catastrophic risk for the country, using probabilistic metrics.

2 Evaluation method

2.1 Introduction

Risk has been defined, for management purposes, as the potential economic, social and environmental consequences of hazardous events that may occur in a specified period of time. However, in the past, the concept of risk has been defined in a fragmentary way in many cases, according to each scientific discipline involved in its appraisal. From the perspective of this article, risk requires a multidisciplinary evaluation that takes into account not only the expected physical damage, the number and type of casualties or economic losses, but also the conditions related to social fragility and lack of resilience conditions related to the community development. For example, at the national scale, the vulnerability as an internal risk factor should be related with the physical exposure and susceptibility and the social fragility and lack of resilience of each region in the country, this means the capacity to respond and absorb the impact. The deficiencies of information, communication and knowledge among actors in society, the absence of institutional and community organization, weaknesses in preparations to attend to emergencies, political instability, and the lack of economic welfare in a geographical area are all factors that help to increase the risk. Therefore, the potential consequences are not only related to the direct impact of an event, but also to the capacity to withstand the impact, and the implications for the geographical area considered.

As part of what is defined as risks of context, we must take account of the absence of economic and social development, weaknesses in society to absorb impact, deficiencies in institutional action, and the lack of capacity to respond in the event of a disaster. The context risk attempts to reflect the conditions of this social deterioration, in the most appropriate possible manner. In relative terms, an area which experiences a high level of social deterioration is more vulnerable, and therefore is at greater risk. The lack of resilience, defined as the inverse of economic, social and institutional capacity to absorb the impact of the crisis, represents the lack of capacity in the community to make an efficient response in the event of an emergency, and deficiencies in institutional actions and governance (lack of effective capacity to anticipate events, respond, and recover).

While it is true that some social circumstances can be considered as matters related to vulnerability, in terms of disasters, those factors cannot always be considered as vulnerability in itself. One example is the factor of poverty, which can be considered as a factor or cause of vulnerability for certain types of event. However, poverty in itself is not synonymous with vulnerability. Therefore, a careful study must be made of the factors making social groups more vulnerable to the phenomena that characterise threats. Without doubt, many disasters today are the product of economic and political factors, often aggravated by pressures that concentrate groups of the population in dangerous places. In most cases, a reduction of vulnerability is indissolubly linked to intervention in the most important basic development needs; and for this reason we can say that there is a relationship between conditions of economic marginality and vulnerability in terms of disasters. The vulnerability of human settlements is intimately linked to the social processes which take place there, and is related to fragility, susceptibility, or lack of resilience of exposed elements in the face of threats of different kinds. Further, vulnerability is intimately linked to environmental degradation, not only in the cities, but in general in an intervened natural environment or in an environment in a process of transformation.

In other words, the risk depends on physical aspects, but also on the intangible impact of a social, economic and environmental nature. That impact in turn depends on a series of factors which aggravate the situation - sometimes called indirect effects - which depend on social situations of context and on resilience. There are aspects of vulnerability which are not always dependent on the threat. From an engineering point of view, vulnerability becomes a risk (a level of expected consequences) when we define the degree of threat that we wish to establish for potential consequences, but the description of that "condition which favours or facilitates" the occurrence of any particular event, and that it might have certain consequences, is a function which is not marked by any defined point in time. If we can define the level of intensity of the event in probabilistic terms, time is included, given that the probability is established for a certain lapse of time. In this way, we can establish the potential loss, damage or consequences, which are therefore now a value, expressed in terms of probability, and can be called a risk. If we accept the hypothesis that there is a strong relationship between lack of development and vulnerability, Cardona (2001; 2003) proposes the following factors as the origins of vulnerability:

a) *Exposure,* which is a condition of susceptibility of a human settlement to suffer adverse effects, because it is in the area of influence of hazardous phenomena, and because of its physical fragility in the face of them.
b) *Social fragility.* This refers to a predisposition that arises as a result of levels of marginality and social segregation of a human settlement, and its conditions of relative disadvantage and weakness, due to social and economic factors.
c) *Lack of resilience,* which expresses limitations of access and mobilisation of resources of the human settlement, inability to anticipate and respond effectively, and deficiencies in absorbing impact.

From a holistic point of view, it will be necessary to consider a wide range of variables, whose treatment is not always facilitated by functions. For this reason, we must use proxy or "representative" functions, which may well be indices or indicators. At the same time, we can say that vulnerability has certain components that reflect susceptibility and physical fragility (exposure) – they have a dependence on the action or severity of the phenomenon- and others which reflect social fragility fragility and lack of resilience - that is, the ability to anticipate, recover and absorb impact; and they are not so dependent, or are not so conditional on the action of the phenomenon. One example would be a good institutional organisation, good governance, the good quantities of health services, a high level of economic stability, amongst other things, which could be considered as resilience factors. Their absence, or lack of these qualities or capacities, is manifest in vulnerability, but it is a "prevalent", "characteristic", "unaware" and "intrinsic" vulnerability, which is of special interest from the point of view of the social sciences. In summary, there is a certain susceptibility and social fragility and a certain lack of resilience that are expressed in a prevalent vulnerability, that "aggravates" the direct impact of damage caused by the action of the phenomenon, and a conditional or dependent vulnerability of the threat, which qualifies direct damage in the social and material context. This type of proposal attempts to make a holistic integration of the readings of the physical sciences and the social sciences, in order to produce a more complete vision of factors which originate or exacerbate vulnerability, taking account of the aspects of physical resistance to phenomena, and the prevalent features of individual and collective self-protection (Cardona and Barbat, 2000).

The evaluation of risk using indicators is a technique developed in order to be able to effect measurements and monitoring over time, and to identify conditions of insecurity and its causes, using criteria related to the degree of seismic threat to which the territorial units that make up the country are exposed, and the socioeconomic circumstances which influence their vulnerability. The evaluation of the risk described and applied here is based on a holistic approach to evaluation, which due to its flexibility and possible compatibility with other approaches to specific evaluation will be increasingly used over time, and accepted as one of the best options to represent situations of risk, due to the complex and imprecise nature of the risk. Its strength lies in the possibility of breaking down results and identifying factors to which risk-reducing actions should be directed, in order to make an evaluation of the effectiveness. The principal objective is not "to reveal the truth", but to provide information and analysis in order to stimulate and improve "decision-making" - that is, the concept which underlies it is control, and not a precise evaluation of the risk, a notion commonly supported by the concept of physical truth.

2.2 Conceptual framework for a holistic approach

The conceptual framework and model for a disaster risk evaluation, from a holistic standpoint, was proposed by Cardona at the end of the 1990s (Cardona, 2001), and he applied it with Hurtado and Barbat in 2000. These works evaluated the risk of disaster, taking account of the range of dimensions or aspects of vulnerability which can be subdivided into three categories or factors in vulnerability:

a) *Exposure and physical susceptibility*, D, which is designated as “hard” risk, related to the potential damage on the physical infrastructure and environment,
b) *Socio-economic fragilities,* F, which contribute to “soft” risk, regarding the potential impact on the social context, and
c) *Lack of resilience to cope disasters and recovery*,¬R, which contributes also to “soft” risk or second order impact on communities and organizations.

Figure 2-1describes the theoretical framework mentioned (Cardona and Barbat 2000).

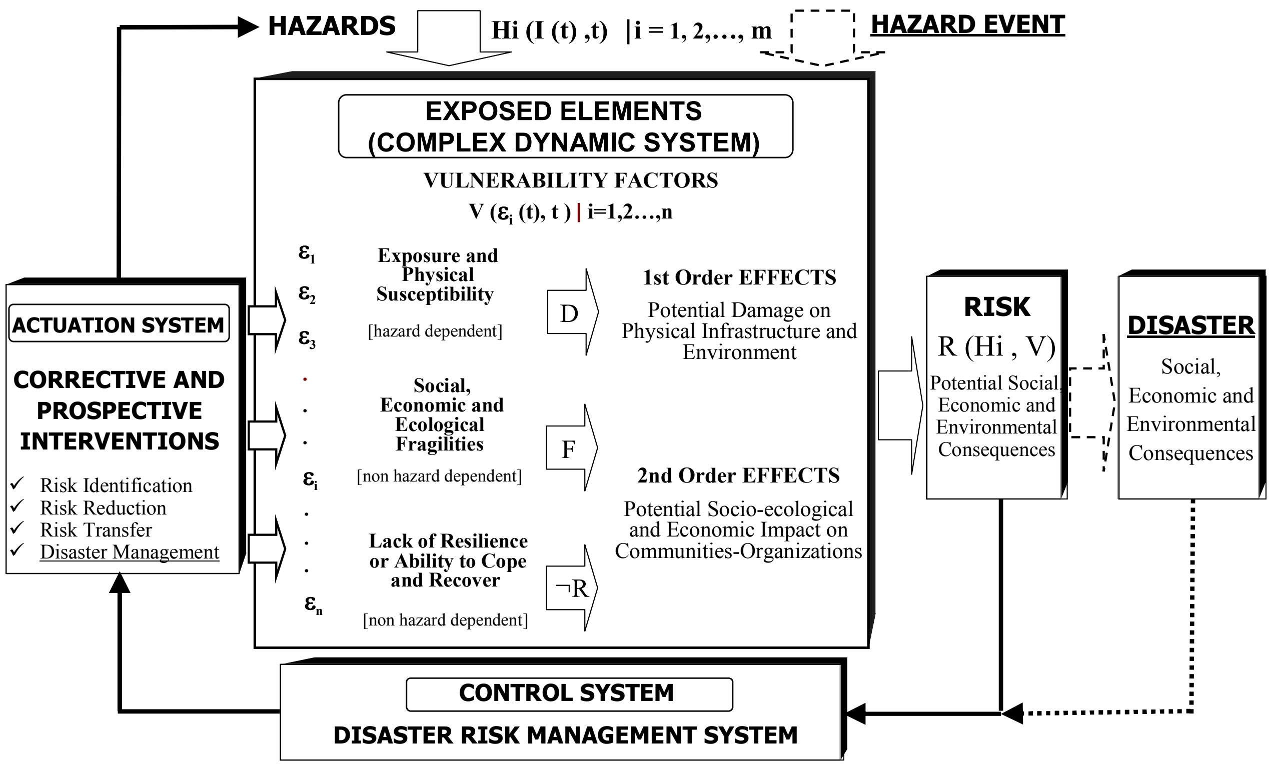

Figure 2-1
Theoretical Framework for a Holistic Approach to Disaster Risk Assessment and Management.
(Source: Adapted from Cardona (1999), Cardona and Barbat (2000), IDEA (2005a/b) and Carreño, Cardona and Barbat (2007a).)

According to this model, vulnerability conditions in disaster prone areas depend on exposure and susceptibility of physical elements, the socioeconomic fragility and the lack of social resilience of the context. These factors provide a measure of direct as well as indirect and intangible impacts of hazard events. Vulnerability, and therefore, risk are the result of inadequate economic growth, on the one hand, and deficiencies that may be corrected by means of adequate development processes. Indicators or indices could be proposed to measure vulnerability from a comprehensive and multidisciplinary perspective. Their use intend to capture favorable conditions for direct physical impacts (exposure and susceptibility), as well as indirect and, at times, intangible impacts (socioeconomic fragility and lack of resilience) of hazard events. Therefore, according this approach (Cardona 2001), exposure and susceptibility are necessary conditions for the existence of physical or "hard" risk, and these are hazard dependent. On the other hand, the propensity to suffer negative impacts, as result of the socioeconomic fragilities, and not being able to adequately face disasters are also vulnerability conditions for risk of the context, or "soft" risk, which usually are non hazard dependent.

Disaster risk, from a holistic perspective, means economic, social and environmental consequences of physical phenomena. These potential consequences are the result of the convolution of hazard events and the vulnerability. For risk management it is desired having a control and an actuation system that represent the risk management institutional organization and the corrective and prospective intervention measures.

Carreño (2006) developed an alternative version of the model, in which the evaluation of risk is achieved affecting the physical risk with an impact factor obtained from contextual conditions, such as the socio-economic fragilities and the lack of resilience; both conditions aggravate the physical loss scenario. Figure 2-2 shows the new version of the model from the holistic perspective originally proposed (Carreño et al 2005).

From a holistic perspective risk, R, is a function of the potential physical damage, D_{φ}, and an aggravating coefficient, I_f. The former is obtained from the susceptibility of the exposed elements, γD_i, to hazards, H_i, regarding their potential intensities, I, of events in a period of time t, and the latter depends on the social fragilities, γF_i, and the issues related to lack of resilience, γRi, of the disaster prone socio-technical system or context.

Using the meta-concepts of the theory of control and complex system dynamics to reduce risk, it is necessary to intervene in corrective and prospective way the vulnerability factors and, when it is possible, the hazards directly. Then risk management requires a system of control (institutional structure) and an actuation system (public policies and actions) to implement the changes needed on the exposed elements or complex system where risk is a social process.

Public policies of risk management include decision-making regarding identification of risk, risk reduction, disaster management, and risk transfer. Risk identification entails the representation and objective assessment of risk, individual perceptions, and how those perceptions are understood by society as a whole. Risk reduction involves prevention and mitigation measures. Disaster management involves emergency response, recovery and reconstruction. And, finally, risk transfer means financial protection.

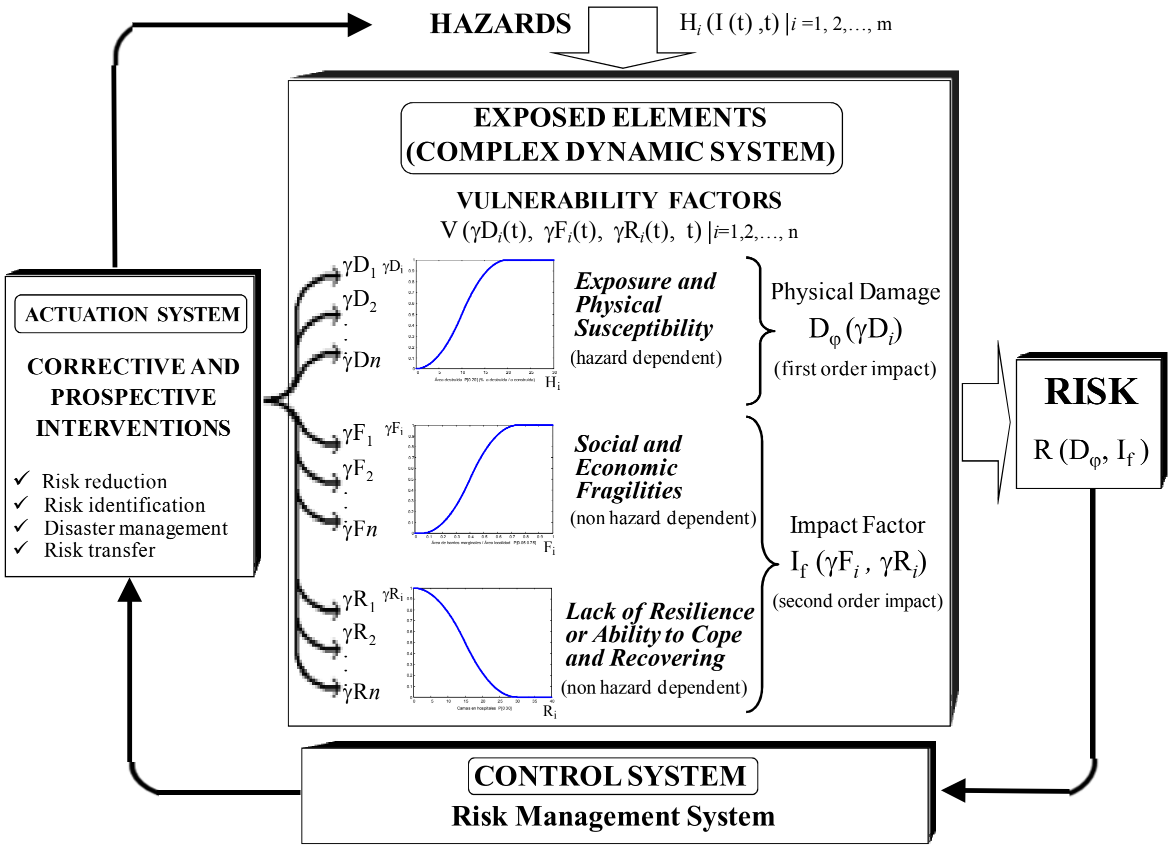

Figure 2-2

Version of the Theoretical framework and model for holistic approach of disaster risk

(Carreño et al 2005)

2.3 Calculation process

This holistic evaluation of risk uses the technique developed by Cardona (2006), at which is made on the basis of input descriptors or variables that take account of physical risk and the context risk. The descriptors of physical risk are obtained from the available physical risk scenarios and the descriptors of the risk of the context come from information about social fragility and lack of resilience of the units of analysis. The descriptors of context risk factors that "aggravate" physical risk, or the direct impact of event. So, the total risk can be expressed using compound indicators or indices, using Equation 1 as follows:

$$R_T = R_{Ph}(1+F) \quad \textbf{(Eq. 1)}$$

expression known as the Moncho's Equation in the field of disaster risk indicators[1], where R_T is the total risk index, R_{Ph} is the physical risk index and F is the aggravating coefficient.

[1] This name was given by a groun of experts during a workshop of the IDB-IDEA project, on risk indicators, developed in November 2003 in Barcelona.

This coefficient, F, depends on the weighted sum of a set of aggravating factors related to the socio-economic fragility, F_{SFi}, and the lack of resilience of the exposed context, F_{LRj}.

Figure 2-3 gives a schematic illustration of the calculation procedure required to obtain each of the indices mentioned in each unit of analysis, and suggest the type of indicators to be used in each case [2]

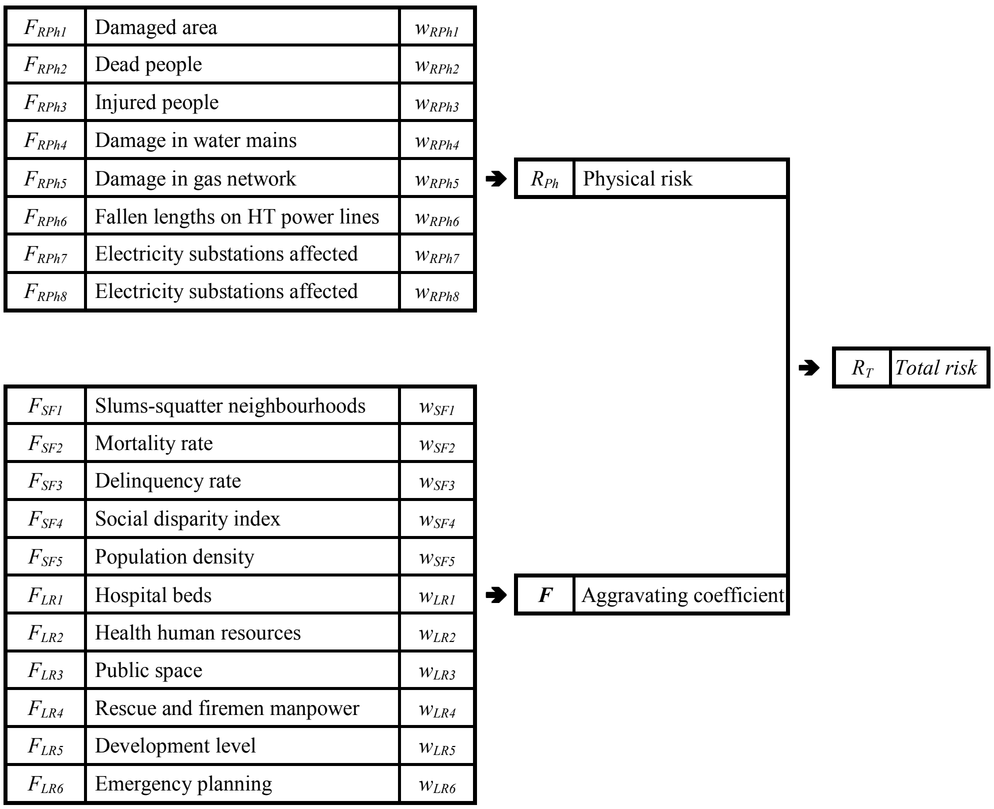

Figure 2-3
Factors of physical risk, social fragility and lack of resilience and their weights

The physical risk index R_{Ph} is obtained as the weighted sum of the physical risk factors, as it is indicated by equation 2

$$R_{Ph} = \sum_{i=1}^{p} F_{RPhi} . w_{RPhi} \qquad \textbf{(Eq. 2)}$$

where p is the total number of descriptors of physical risk index, F_{RPhi} are the component factors and w_{RPhi} are their weights respectively. These weights represent the relative importance of each factor and are calculated by means of the Analytic Hierarchy Process

[2] The indicators suggested in the example, or their equivalents, have been been partly or fully used in previous applications for Barcelona, Bogota, Manizales, Metro-Manila and Istanbul.

(AHP), which is used to derive ratio scales from both discrete and continuous paired comparisons (Saaty, 2001). Table 2-1 presents variables proposed to describe the physical risk, and the units that we recommend should be used to obtain those descriptors for each town or area of analysis.

Table 2-1
Physical risk descriptors and their units

Descriptor		Units
X_{RPh1}	Damaged area	Percentage (damaged area / build area)
X_{RPh2}	Dead people	Number of dead people each 1000 inhabitants
X_{RPh3}	Injured people	Number of injured people each 1000 inhabitants
X_{RPh4}	Ruptures in water mains	Number of ruptures / Km2
X_{RPh5}	Rupture in gas network	Number of ruptures / Km2
X_{RPh6}	Fallen lengths on HT power lines	Metres of fallen lengths / Km2
X_{RPh7}	Telephone exchanges affected	Vulnerability index
X_{RPh8}	Electricity substations affected	Vulnerability index

The physical risk factors are calculated by mean of a normalization process using the transformation functions shown in figure 2-2. These functions standardize the gross values of the descriptors (number of dead people, injured, etc) transforming them in commensurable factors with values between 0 and 1.

The aggravating coefficient, F, is evaluated in the same way, as the weighted sum of a set of aggravating factors related to the socio-economic fragility, it is shown by equation 3,

$$F = \sum_{i=1}^{m} F_{SFi} \cdot w_{SFi} + \sum_{j=1}^{n} F_{LRj} \cdot w_{LRj} \qquad \textbf{(Eq. 3)}$$

were F_{SFi} are the social fragility factors, F_{LRj} are the lack of resilience factors, m and n are the number of factors, w_{SFi} y w_{LRj} are the weights for each aggravating factor. These weightings add up to 1, and are obtained by using the PAJ explained below. Table 2-2 presents indicators or variables proposed to describe social fragility and lack of resilience, and the units used in each descriptor.

Table 2-2
Aggravating descriptors, their units and identifiers

Descriptor		Units
X_{SF1}	Slums-squatter neighbourhoods	Slum-squatter neighbourhoods area / Total area
X_{SF2}	Mortality rate	Number of deaths each 10000 inhabitants
X_{SF3}	Delinquency rate	Number of crimes each 100000 inhabitants
X_{SF4}	Social disparity index	Index between 0 and 1
X_{SF5}	Population density	Inhabitants / Km2 of build area
X_{LR1}	Hospital beds	Number of hospital beds each 1000 inhabitants
X_{LR2}	Health human resources	Health human resources each 1000 inhabitants
X_{LR3}	Public space	Public space area/ Total area
X_{LR4}	Rescue and firemen manpower	Rescue and firemen manpower each 10000 inhabitants
X_{LR5}	Development level	Qualification between 1 and 4
X_{LR6}	Risk management index	Index between 0 and 1*

The aggravating factors are calculated by mean of a normalization process using the transformation functions shown in the figures 2-3 and 2-4. These functions standardize the gross values of the descriptors transforming them in commensurable factors with values between 0 and 1.

According to Zapata (2004), it is estimated that the indirect economic effects of a natural disaster depend on the type of phenomenon. The order of magnitude of the indirect economic effects for a 'wet' disaster (as one caused by a flood) could be of 0.50 to 0.75 of the direct effects. In the case of a 'dry' disaster (caused by an earthquake, for example), the indirect effects could be about the 0.75 to 1.00 of the direct effects, due to the kind of damage (destruction of livelihoods, infrastructure, housing, etc.). This means that the total risk, R_T, could be between 1.5 and 2 times R_{Ph}. In this method, the maximum value selected was the latter. For this reason, the aggravating coefficient, F, takes values between 0 and 1 in Equation 1, this means that the value of R_T is between one to two times R_{Ph}.

2.4 Transformation functions

Using the procedure described above for an area of study formed by units of analysis, such as a department, province, city district, metropolitan district, commune, etc, the total risk for each type of the unit of analysis is obtained by estimating the factors of physical risk and aggravation due to social fragility and lack of resilience. These factors are obtained by scaling a series of descriptors which have been defined as the basis in available information, and which best reflect what is wanted, avoiding the simultaneous use of variables which express the same aspect, in order to avoid double-valuation. This transformation of descriptors into factors is intended to scale the range of variables in compatible units, which can make a commensurable analysis. The area of public space for the massive attention cannot be directly related to individuals and rescue personnel, for example, because the former is expressded in square metres, and the latter in numbers of individuals.

In order to express the result of the index R_{Ph} and F, as a linear combination of relative indicators implies that there is no interaction between them, or between those variables and the weightings used. This is not very realistic, but is sometimes considered to be acceptable, given the uncertainties or inaccuracies inherent in data, and the need for simplification. However, it may become increasingly appropriate and desirable to obtain risk indices by using non-linear functions that are gradually perfected, given the complexity associated with the notion of risk, because this allows comparisons to be made between results in a way that would not be possible to do if only values related to the interior of the geographical area analyzed were involved. For this purpose, we need to assume certain forms of the functions and their extreme values with the support of experts, taking account of available information from previous disasters. In the case of risk, most of these functions - which would have a role as norms or references-points - may adopt sigmoid forms, since it is considered that they are the most appropriate forms, and that they have been widely used in estimating physical vulnerability. The use of the same group of functions, despite the fact that they may be hypothetical, to obtain the factors for the index R_{Ph} and F, solves the problem of incommensurability of the units of the descriptors, and establishes a uniform scheme for the standard valuation of risk.

Figure 2-4, shows the model wich follows the trasformation funtions proposed and applied by Carreño (2006) for the estimations of physical risk and aggravation factors. The *x* axis has values of the descriptors, while the value of the factor (physical risk or aggravation) is in the *y* axis, taking values between 0 and 1. The limit values, X_{min} and X_{max}, are defined taking into account the expert opinions and information about past disasters. In the case of the descriptors of lack of resilience, the function has the inverse shape; the higher value of the indicator gives lower value of aggravation.

The use of transformation functions in the calculation of risk indices permits a comparison of results (for example, at different moments of time, or between different cities or countries), and the setting of categories or rankings, provided that similar indicators are used, and the same weighting is applied for factors obtained. Both the transformation functions and the weightings, whose estimations are described below, are reference-points which may be casual or deliberate, such as in an estimate of physical damage or loss for a specific return period in the most rigorous terms of risk evaluation. However, they are remarkably useful, because they allow benchmark-measurements to be made using reference points, based on the good judgement and uniform criteria of the experts who have supported this work. The use of this type of reference-point is what facilitates the measurement of multiple attributes - multi-criterion evaluation - and the comparison of aspects of risk which cannot be measured, and combined directly.

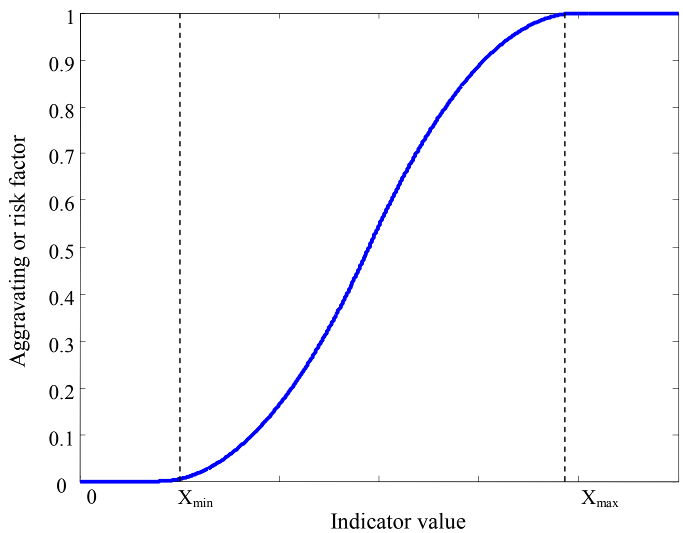

Figure 2-4
Model of the transformation functions

2.5 Weighting factors

Once the descriptors have been scaled and converted into commensurable indicators - that is, factors - weightings should be established, depending on their contribution or relative importance in the index of which they form part. The "share" assigned to each factor illustrates how important it is - how much it weighs - in comparison to the other factors in the composition of the physical risk index, and the coefficient of aggravation. These indices attempt to capture collective knowledge of all the experts who take part in the weighting process, in order to establish the most appropriate possible values. Several weighting techniques have been used to construct compound indices or indicators (JRC-EC 2002; 2003). However, all of those proposed on the basis of statistical techniques require either that the dependent variables must be able to be measured directly (for example, through regression), or that the indicators are properly correlated (for example, through an analysis of their principal components). Given that the risk cannot be measured directly, and the indicators are not properly correlated, a technique that contains these requisites will not be the most effective one. The only option which remains for weighting is a subjective evaluation by experts of the contribution or relative importance (weighting), of sub-indicators which compose an indicator or index. Although this technique seems to be undesirable for some, due to the lack of an explicitly replicable base, characteristic evaluations in what is known as post-normal science (Funtowicz and Ravetz, 1992), such as the risk of disasters, this is the only option feasible and reasonable to capture the criterion, the experience, and the judgment of experts. There are a number of possibilities, ranging from the simplest, known as the allocation of scores or "budget" to the "Delphi" techniques, whose purpose is to achieve results by consensus through processes of anonymous interaction. As an alternative to these techniques, there has been a proposal for the analytical hierarchy process (AHP) which facilitates multi-criterion analysis based on relative importance. It is a useful technique to allocate factors of participation or importance of the components of an indicator in a more rigorous manner than the direct appreciation using "judgement" or "hunches" of experts (Hyman, 1998).

3 Application to Belize

3.1 Basic information

The basis taken for a holistic evaluation of the risk to Belize was composed of the results of physical risk presented in the report ERN-CAPRA-T3.3 (Country Risk Profile, Concentration of Risk and Risk Maps, ERN 2010), made by this consultancy group in the context of the CAPRA platform, and a series of variables which characterise social and context considerations of different Districts of the country, to calculate the physical risk index R_{Ph}

The calculation of the coefficient of aggravation F was based on information found in a number of different local sources.

Belize is divided into six Districts: Cayo, Belize, Toledo, Corozal, Orange Walk and Stann Creek. This study uses the Districts as its unit.

3.2 Physical risk index, R_{Ph}

The evaluation of physical risk for Belize takes account of the threat of hurricane-force winds, since the report ERN-CAPRA-T3.3 concludes that this is the dominant risk for the country, in other words, it is the risk that will bring the greatest losses. The indicators selected for the valuation are shown in Table 3-1.

Table 3-1
Physical risk indicators for Belize

	Indicator	Units
X_{RPh1}	Dead people	# each 100.000 inhabitants
X_{RPh2}	Injured people	# each 100.000 inhabitants
X_{RPh3}	Private construction	premium [‰]
X_{RPh4}	Public construction	premium [‰]
X_{RPh5}	Urban infrastructure	premium [‰]
X_{RPh6}	National infrastruture	premium [‰]
X_{RPh7}	Water and sewerage network	premium [‰]
X_{RPh8}	Gas network	premium [‰]
X_{RPh9}	Electricity networks	premium [‰]
X_{RPh10}	Electricity substations	premium [‰]
X_{RPh11}	Telephone exchanges	premium [‰]
X_{RPh12}	Road network	premium [‰]

Table 3-2 presents values for the indicators selected for the Districts. Figure 3-1 presents the transformation functions used to standardize these indicators, and Table 3-3 presents factors obtained from this transformation and the results for the physical risk index $R_{Ph.}$ Table 3-4 presents the weightings corresponding to each factor used in the calculation.

Figure 3-1 presents the functions corresponding to indicators for fatalities, injuries, and the premium for private construction (which is the same as for national and urban-scale infrastructure), and the corresponding premium for the water supply, (which is the same as other vital lines in Table 3-1).

Table 3-2
Physical risk indicators for Belize

District	X_{RPh1}	X_{RPh2}	X_{RPh3}	X_{RPh4}	X_{RPh5}	X_{RPh6}	X_{RPh7}	X_{RPh8}	X_{RPh9}	X_{RPh10}	X_{RPh11}	X_{RPh12}
Cayo	1	1	12.90	12.17	4.55	0.02	0.00	0.00	6.36	8.90	9.83	0.00
Belize	1	1	17.42	16.61	6.76	0.81	0.00	0.00	13.57	13.36	13.33	0.02
Toledo	1	1	11.54	10.73	6.65	0.01	0.00	0.00	8.18	8.57	10.00	0.01
Corozal	1	2	17.54	16.37	5.57	0.56	0.00	0.00	9.39	10.00	13.33	0.00
Orange Walk	1	1	16.06	15.12	10.03	0.01	0.00	0.00	8.33	10.86	12.06	0.00
Stann Creek	1	1	15.88	14.91	3.89	0.04	0.00	0.00	11.90	11.85	13.33	0.02

Table 3-3
Physical risk factors and Physical risk index for Belize

District	F_{RPh1}	F_{RPh2}	F_{RPh3}	F_{RPh4}	F_{RPh5}	F_{RPh6}	F_{RPh7}	F_{RPh8}	F_{RPh9}	F_{RPh10}	F_{RPh11}	F_{RPh12}	R_{Ph}
Cayo	0.08	0.002	0.96	0.93	0.18	0	0	0	1	0.67	1	0	0.41
Belize	0.08	0.002	1	1	0.41	0.006	0	0	1	0.98	1	0.00003	0.44
Toledo	0.08	0.002	0.89	0.84	0.39	0	0	0	1	0.63	1	0.000008	0.40
Corozal	0.08	0.009	1	1	0.28	0.003	0	0	1	0.78	1	0	0.43
Orange Walk	0.08	0.002	1	1	0.78	0	0	0	1	0.85	1	0	0.45
Stann Creek	0.08	0.002	1	0.99	0.13	0	0	0	1	0.91	1	0.00003	0.43

Table 3-4
Weights of the physical risk factors for Belize

Factor	Weight	Calculated weight
F_{RPh1}	w_{RPh1}	0.09
F_{RPh2}	w_{RPh2}	0.09
F_{RPH3}	w_{RPh3}	0.20
F_{RPh4}	w_{RPh4}	0.04
F_{RPh5}	w_{RPh5}	0.04
F_{RPh6}	w_{RPh6}	0.03
F_{RPh7}	w_{RPh7}	0.17
F_{RPh8}	w_{RPh8}	0.11
F_{RPh9}	w_{RPh9}	0.10
F_{RPh10}	w_{RPh10}	0.04
F_{RPh11}	w_{RPh11}	0.04
F_{RPh12}	w_{RPh12}	0.05

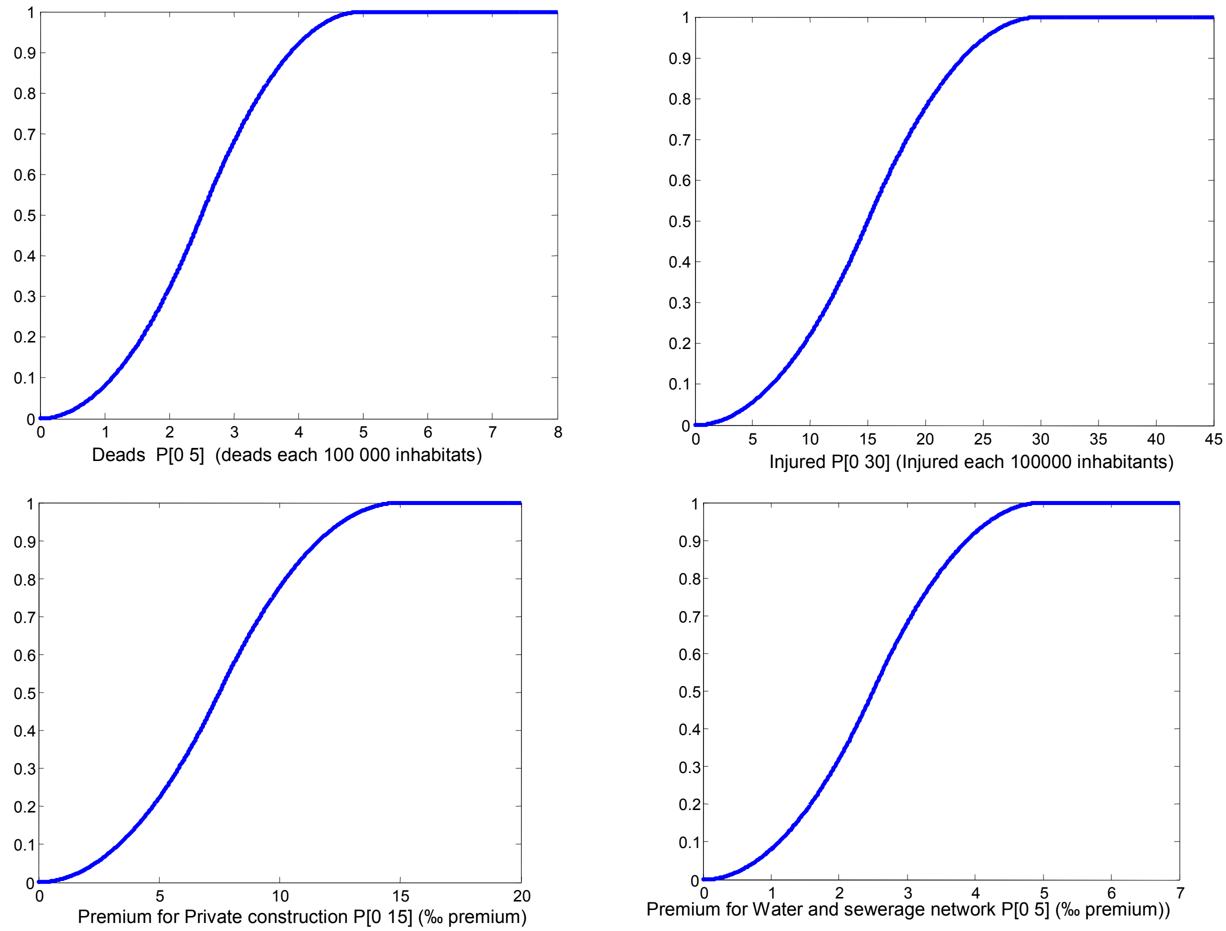

Figure 3-1
Used trasformation functions

Figure 3-2 and Figure 3-3 present results obtained for physical risk due to hurricane-force winds.

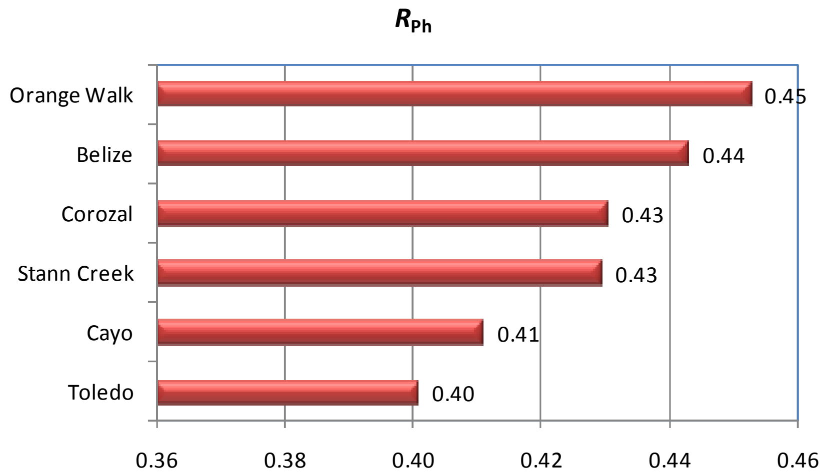

Figure 3-2
Physical risk results for Belize districts

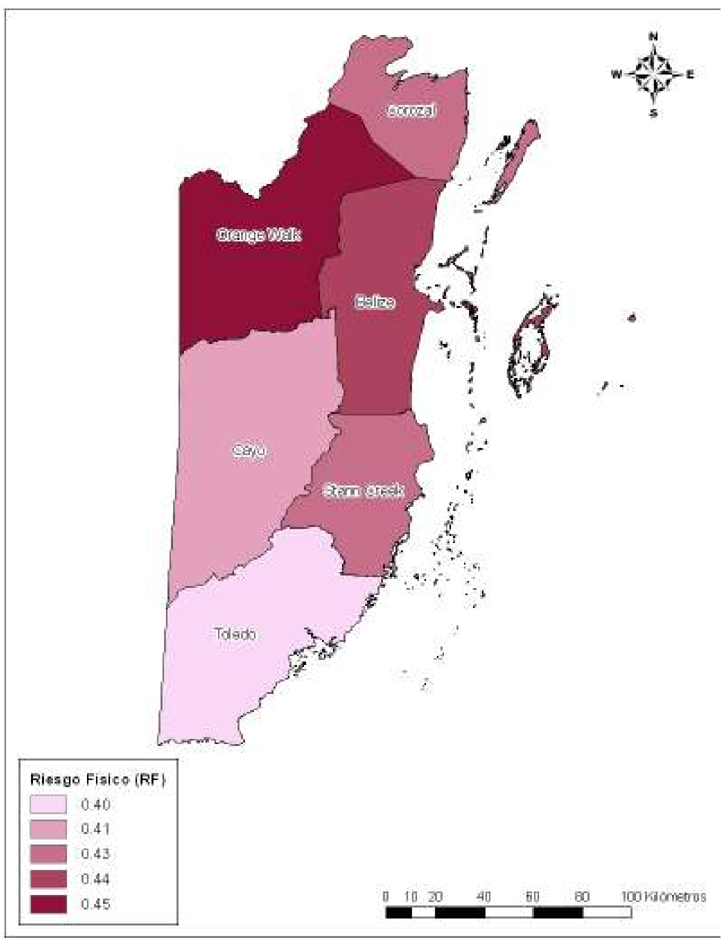

Figure 3-3
Map of the obtained results for physical risk

3.3 Aggravating coefficient, *F*

The basis for the evaluation of conditions of aggravation in Belize was information found in sources such as the Statistical Institute of Belize (SIB)[3] and the Belize Ministry of Health[4]. Table 3-5 shows indicators selected for evaluation, in the light of available information.

Table 3-5
Indicators of aggravating conditions for Belize

	Indicator	Units
X_{SF1}	Population density	inhab / km^2
X_{SF2}	Extreme poverty	index
X_{LR1}	Hospital beds	Beads each 10.000 inhab

Table 3-6 present values for the indicators selected for the Districts. Figure 3-4 presents the transformation functions used to standardize these indicators, and Table 3-7 presents factors obtained from this transformation and the results for the Aggravation Coefficient *F*. Table 3-8 presents weightings of the aggravation factors used in the calculation.

Figure 3-4 presents functions of transformation corresponding to indicators of population density and hospital beds.

Table 3-6
Indicators of aggravating conditions for Belize

District	X_{SF1}	X_{SF2}	X_{LR1}
Cayo	52,715	2.8	11.99
Belize	61,246	2.8	9.85
Toledo	41,466	31.5	19.19
Corozal	41,407	3.3	12.99
Orange Walk	50,652	3.8	13.96
Stann Creek	41,543	3.3	27.97

[3] http://www.satisticsbelize.org.bz

[4] www.health.gov-bz

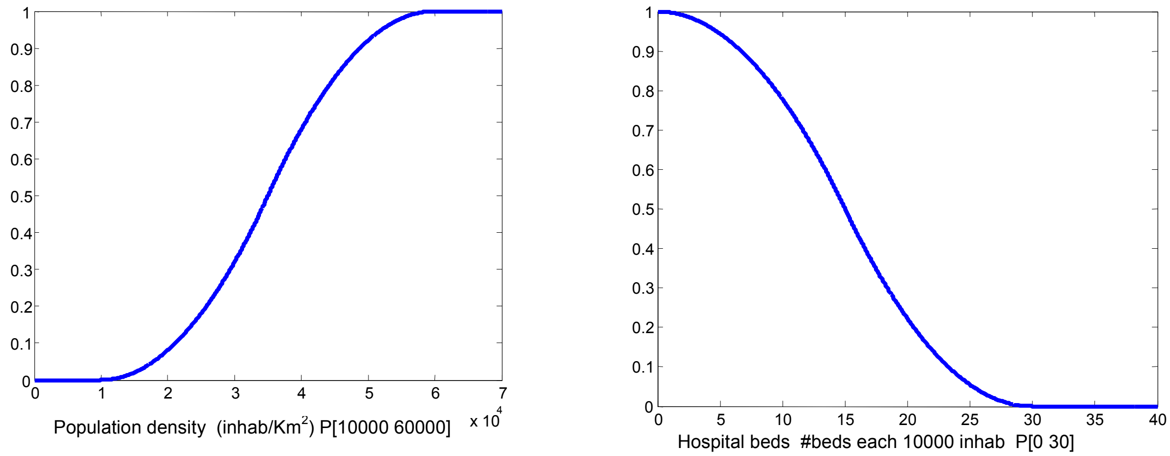

Figure 3-4
Trasformation funcions used

Table 3-7
Factors of aggravating conditions and Aggravating coefficient for Belize

District	F_{SF1}	F_{SF2}	F_{LR1}	F
Cayo	0.96	0.028	0.68	0.57
Belize	1	0.028	0.78	0.62
Toledo	0.73	0.315	0.26	0.42
Corozal	0.72	0.033	0.63	0.48
Orange Walk	0.93	0.038	0.57	0.52
Stann Creek	0.73	0.033	0.01	0.23

Table 3-8
Weights of Aggravating factors for Belize

Factor	Weight	Calculated weight
F_{SF1}	w_{SF1}	0.3
F_{SF2}	w_{SF2}	0.3
F_{LR1}	w_{LR1}	0.4

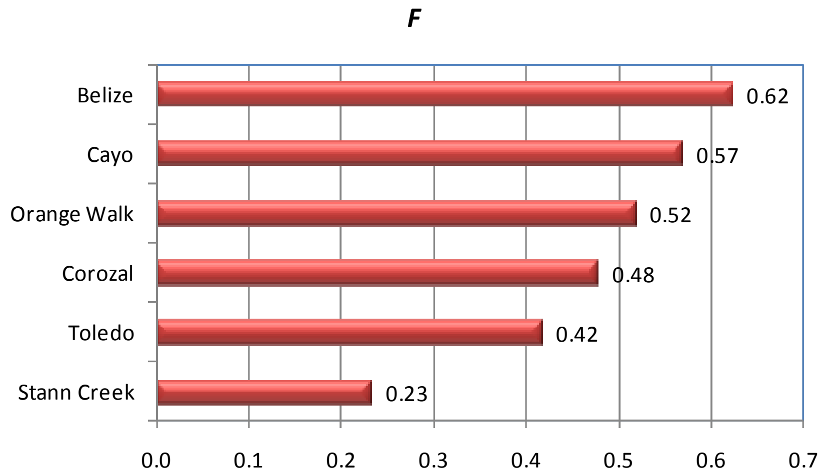

Figure 3-5
Obtained results of the Aggravating coefficient for the districts of Belize

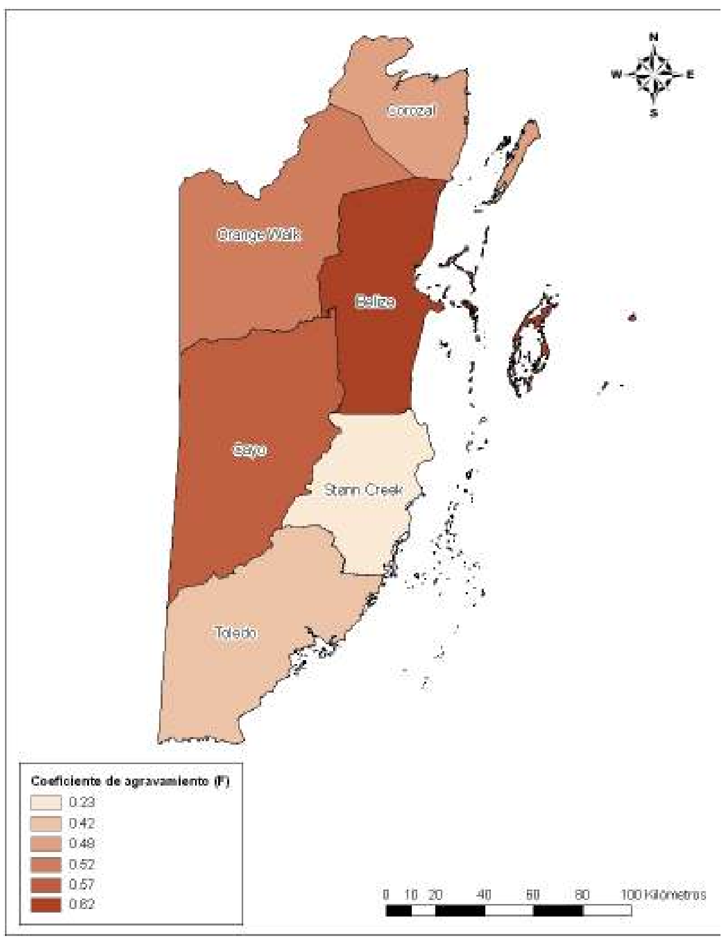

Figure 3-6
Map of the obtained results for the Aggravating coefficient

3.4 Total risk, R_T

Total risk is obtained after calculating the component items in the index. Table 3-9 and Figure 3-7 present the values of the total risk index for each District.

Table 3-9
Total risk for Belize

District	R_{Ph}	F	R_T
Cayo	0.41	0.57	0.64
Belize	0.44	0.62	0.72
Toledo	0.40	0.42	0.57
Corozal	0.43	0.48	0.64
Orange Walk	0.45	0.52	0.69
Stann Creek	0.43	0.23	0.53

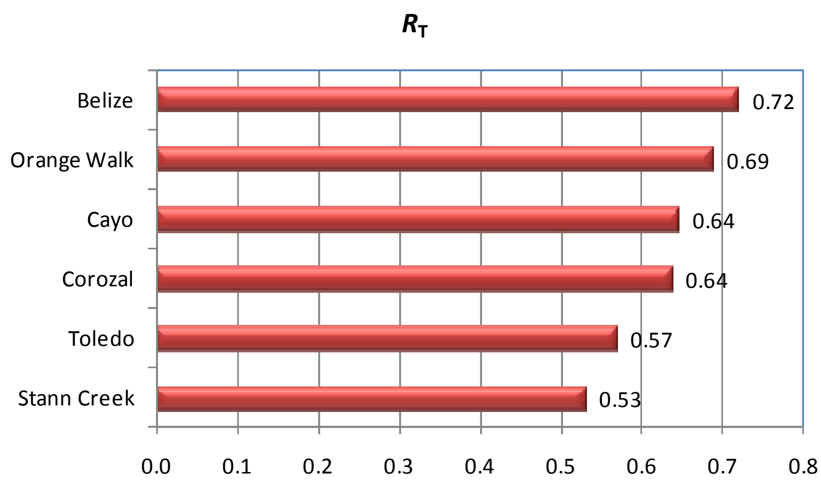

Figure 3-7
Obtained results of Total risk for the districts of Belize

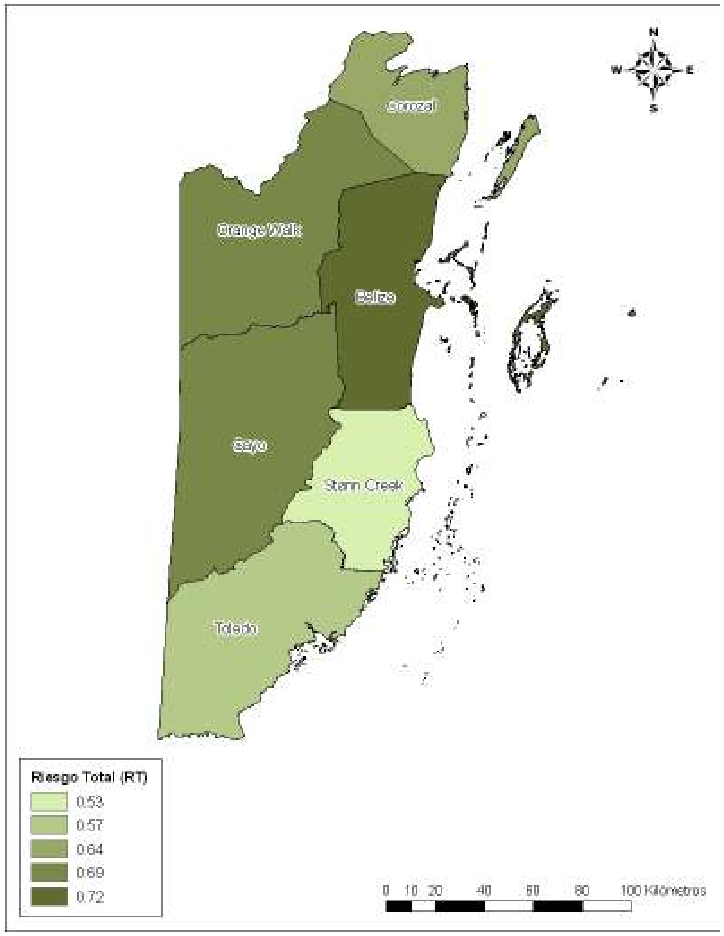

Figure 3-8
Total risk map for Belize

4 Final comments

Risk estimates made from a holistic standpoint enabled us to make a classification or ranking of the relative risks in territorial units, and to identify those which present the highest level of physical risk, and those which present the social, economic or environmental conditions which would tend to make the risk higher, should a disaster occur. On that point, we were able to show that the Districts of Belize and Orange Walk are the Districts that present the highest total risk.

However, the Districts of Belize and Cayo are those which offer the highest degree of aggravation due to conditions of social fragility and lack of resilience. The District of Stann Creek is in the best position, with the lowest coefficient of aggravation in the country.

Table 4-1 identifies indicators of social fragility and lack of resilience which contribute most to worsen the aggravation coefficient, for each District.

If regular evaluations are made, it will be possible to identify differences and changes in variables and results for the risks derived from them. In the case of prospective and corrective interventions, which involve changes as a result of activities in prevention and in general of development, it will be possible to identify the benefit of those interventions dynamically. In other words, it will be easy to update the value of the variables, and this will be of advantage when making sensitivity analyses and calibrating the model. This particular aspect of the integral focus for risk evaluation, which starts from an evaluation of direct effects, will enable the risk to be monitored, along with the effectiveness of measures taken in prevention or mitigation. Finally, it will be possible to identify the most important aspects of risk, without making great efforts in the analysis and interpretation of results.

Table 4-1
Aggravating conditions with the greater contributions for the Belize districts

District	Indicator
Cayo	Population density and hospital beds
Belize	Hospital beds and population density
Toledo	Population density and hospital beds
Corozal	Hospital beds and population density
Orange Walk	Population density and hospital beds
Stann Creek	Population density and extreme poverty

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