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Holistic evaluation of the seismic risk in urban centers

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Summary

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. At nowadays, the risk is defined, for management purposes, as the potential economic, social and environmental consequences of hazardous events that may occur in a specified period of time. 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, which favors the second order effects when a hazard event strike a urban centre. The urban seismic risk evaluation is proposed from a holistic point of view; that is an integrated and comprehensive approach to guide decision-making. Evaluation of the potential physical damage is the first step of this method. Subsequently, a set of social context conditions that aggravate the physical effects are also considered. In the method here proposed, the holistic risk evaluation is based on urban risk indicators. According to this procedure, a physical risk index is obtained, for each unit of analysis, from existing loss scenarios, whereas the total risk index is obtained by factoring the former index by an impact factor, based on variables associated with the socio-economic conditions of each unit of analysis. Finally, examples of the model application are given for two urban centers: Bogotá and Barcelona

KEYWORDS: risk evaluation, seismic risk, urban centers.

1. METHODOLOGY OF EVALUATION

The report Natural Disasters and Vulnerability Analysis [UNDRO, 1980] proposed the unification of disaster related definitions as hazard (H), vulnerability (V), exposed elements (E) and risk (R) and suggested one expression to associating them, that is considered a standard at present

$$R = E \cdot H \cdot V \tag{1}$$

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Based on this formulation several methodologies for risk assessment have been developed from different perspectives in the last decades, and recently a holistic approach for the case of urban centers [Cardona and Hurtado 2000; Masure, 2003].

Cardona (2001) developed a conceptual framework and a model for seismic risk analysis of a city from a holistic perspective. It considers both "hard" and "soft" risk variables of the urban centre, taking into account exposure, socio-economic characteristics of the different districts of the city and their disaster coping capacity or degree of resilience. The model was made to guide the decision-making in risk management, helping to identify the critical zones of the city and their vulnerability from different professional disciplines.

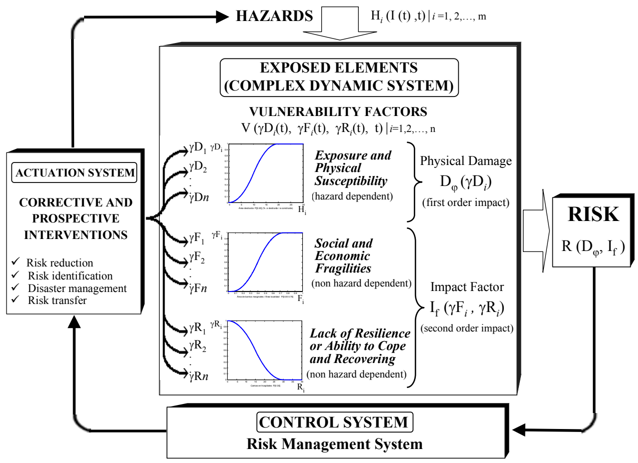

Figure 1. Model for holistic approach of disaster risk (adapted from [3])

This article presents an alternative method for urban risk evaluation based on Cardona's model [Cardona, 2001; Barbat and Cardona, 2003], using a holistic approach and describing seismic risk by means of indices. Expected building damage and losses in the infrastructure, obtained from future loss scenarios are basic information for the evaluation of physical risk in each unit of analysis. Starting from these data, a physical damage index is obtained.

The holistic evaluation of risk by means of indices is achieved affecting the physical risk with an impact factor or aggravating coefficient, obtained from contextual conditions, such as the socio-economic fragility and the lack of resilience, that aggravate initial physical loss scenario. Available data about these conditions at urban level are necessary to apply the method. An explanation of the model is made ahead and also some examples of application for the cities of Bogotá, Colombia, and Barcelona, Spain, are described to illustrate the benefits of this approach that contributes to the effectiveness of risk management, inviting to the action identifying the hard and soft weaknesses of the urban centre. Figure 1 shows the theoretical framework for the alternative model.

From a holistic perspective risk, R, is a function of the potential physical damage, D_j, and an impact factor, I_f. The former is obtained from the susceptibility of the exposed elements, γ_{Di}, 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, γ_{Fi}, and the issues related to lack of resilience, γ_{Ri}, 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 the risk is a social process.

In this paper the proposed holistic evaluation of risk is performed using a set of input variables, herein denominated descriptors. They reflect the physical risk and the aggravating conditions that contribute to the potential impact. Those descriptors, listed forward, are obtained from the loss scenarios effects and from socio-economic and coping capacity information of the exposed context [Barbat and Cardona, 2003; Carreño et al., 2005]. The obtainment or calculation of these descriptors is not the objective of this paper. More information on this subject can be found in Carreño et al. (2005). They are only input information data. The socio-economic fragility and the lack of resilience are a set of factors (related to indirect or intangible effects) that aggravate the physical risk (potential direct effects). Thus, the total risk depends on the physical risk, and the indirect effects expressed as a factor

$$R_T = R_F(1+F) \tag{2}$$

In this equation, known as Moncho's equation, R_T is the total risk index, R_F is the physical risk index and F is the impact factor. This coefficient, F, depends on the weighted sum of a set of aggravating factors related to the socio-economic fragility, F_{FSi}, and the lack of resilience of the exposed context, F_{FRj}

$$F = \sum_{i=1}^{m} w_{FSi} \times F_{FSi} + \sum_{j=1}^{m} w_{FRj} \times F_{FRj} \tag{3}$$

where w_{FSi} and w_{FRj} are the weights or influences of each i and j factors and m and n are the total number of descriptors for social fragility and lack of resilience respectively.

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The aggravating factors F_{FSi} and F_{FRj} are calculated using transformation functions shown in the figures 2 and 3. These functions standardize the gross values of the descriptors transforming them in commensurable factors. The weights w_{FSi} and w_{FRj} represent the relative importance of each factor and are calculated by means of the Analytic Hierarchy Process (AHP). It is used to derive ratio scales from both discrete and continuous paired comparisons [Saaty, 1980, 2001].

The physical risk, R_F, is evaluated in the same way, using the transformation functions showed in the Figure 3

$$R_F = \sum_{i=1}^{p} w_{RFi} \times F_{RFi} \tag{4}$$

where p is the total number of descriptors of physical risk index, F_{RFi} are the component factors and w_{RFi} are their weights respectively. The factors of physical risk, F_{RFi}, are calculated using the gross values of physical risk descriptors such as the number of deaths, injured or the destroyed area, and so on. The transformation functions take values between 0 and 1 (see figures 2, 3 and 4).

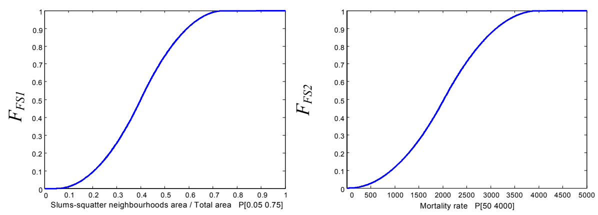

Figure 2. Examples of transformation functions used for the social fragility factors

It is estimated that the indirect effects of hazard events, sized by the factor F in equation 2, can be the same order of the direct effects. According to the Economic Commission for Latin America and the Caribbean (ECLAC), 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 impact, R_T, could be between 1.5 and 2 times R_F. In this method, the maximum value selected was the latter. For this reason, the impact factor, F, takes values between 0 and 1 in equation 2, in this case.

In order to develop the transformation functions sigmoid functions were used (see figures 2 to 4). The maximum and minimum values (for the values 1 or 0 of each factor) were fixed using existing information about disasters as well as experts opinions. For the lack of resilience descriptors, related to the level of development of the community and the emergency planning or preparedness, a linear relation was assumed. Table 1 presents the variables used to reflecting the social fragility and the lack of resilience in the estimation of F.

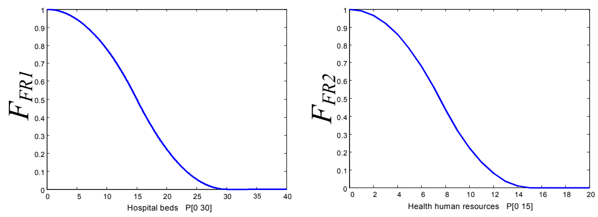

Figure 3. Examples of transformation functions used for the lack of resilience factors

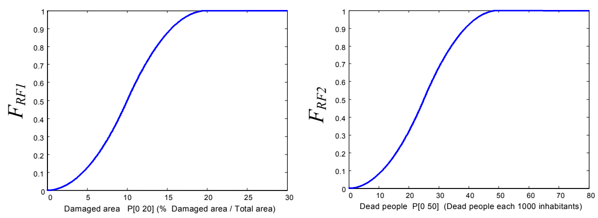

Figure 4. Examples of transformation functions used for the physical risk factors

Figures 2 to 4 show the values of the descriptors in the x-axis of the transformation functions. The corresponding factors, or scaled values, are given in the y-axis.

Table 1. Descriptors used to evaluate the impact factor F

Aspect	Descriptor
Social fragility	Slums-squatter neighbourhoods
	Mortality rate
	Delinquency rate
	Social disparity index
	Population density
Lack of resilience	Hospital beds
	Health human resources
	Public space
	Rescue and firemen manpower
	Development level
	Preparedness emergency planning

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Table 2 presents the initial measurement units of each descriptor of social fragility and resilience. Table 3 shows the descriptors of the physical risk. The factors for a city are obtained in each case using the transformation functions of the aforesaid figures and the variables with the units of tables above-mentioned.

Table 2. Aggravating descriptors, their units and identifiers

Descriptor		Units
X_{FS1}	Slums-squatter neighbourhoods	Slum-squatter neighbourhoods area / Total area
X_{FS2}	Mortality rate	Number of deaths each 10000 inhabitants
X_{FS3}	Delinquency rate	Number of crimes each 100000 inhabitants
X_{FS4}	Social disparity index	Index between 0 y 1
X_{FS5}	Population density	Inhabitants / Km^2 of build area
X_{FR1}	Hospital beds	Number of hospital beds each 1000 inhabitants
X_{FR2}	Health human resources	Health human resources each 1000 inhabitants
X_{FR3}	Public space	Public space area/ Total area
X_{FR4}	Rescue and firemen manpower	Rescue and firemen manpower each 10000 inhabitants
X_{FR5}	Development level	Qualification between 1 and 4
X_{FR6}	Emergency planning	Qualification between 0 and 2

Figure 5 shows the process of calculation of the total risk index for the units of analysis, R_T, starting from the factors of physical risk, F_{RFi}, and of aggravating, F_{FSi} and F_{RFi}, and using the weights w_{RFi}, w_{FSi} and w_{FRi} of each factor. These weights take values according to the expert opinion for each studied city applying the Analytic Hierarchical Process (AHP). Using the factors obtained applying the functions of figures 2 to 4, the physical risk index is calculated by applying equation 4, the impact factor by means of equation 3 and, finally, the total risk is calculated by means of equation 2.

This new model improves conceptual and methodological aspects of the first Cardona's proposal, refining the applied numerical techniques and turning it into a more versatile tool. The conceptual improvements provide a more solid theoretical and analytical support to the new model, eliminating unnecessary and dubious aspects of the previous method, given more transparency and applicability in some cases. The new approach preserves the use of indicators and fuzzy sets or membership functions, proposed originally, but in a different way. It also improves the procedure of normalization and calculates the final indices in an absolute (non relative) manner. This feature facilitates the comparison of risk among cities. Finally, the earlier model takes into account descriptors of physical risk, seismic hazard, physical exposure, socio-economic fragility, and lack of resilience; in the new approach, seismic hazard and the physical exposure have been eliminated because they are redundant due to they have been included into the physical risk variables.

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F_{RF1}	Damaged area	w_{RF1}
F_{RF2}	Dead people	w_{RF2}
F_{RF3}	Injured people	w_{RF3}
F_{RF4}	Damage in water mains	w_{RF4}
F_{RF5}	Damage in gas network	w_{RF5}
F_{RF6}	Fallen lengths on HT power lines	w_{RF6}
F_{RF7}	Electricity substations affected	w_{RF7}
F_{RF8}	Electricity substations affected	w_{RF8}

➔ R_F Physical risk

➔ R_T Total risk

F_{FS1}	Slums-squatter neighbourhoods	w_{FS1}
F_{FS2}	Mortality rate	w_{FS2}
F_{FS3}	Delinquency rate	w_{FS3}
F_{FS4}	Social disparity index	w_{FS4}
F_{FS5}	Population density	w_{FS5}
F_{FR1}	Hospital beds	w_{FR1}
F_{FR2}	Health human resources	w_{FR2}
F_{FR3}	Public space	w_{FR3}
F_{FR4}	Rescue and firemen manpower	w_{FR4}
F_{FR5}	Development level	w_{FR5}
F_{FR6}	Emergency planning	w_{FR6}

➔ F Impact factor

Figure 5. Factors of physical risk, social fragility and lack of resilience and their weights

Table 3. Physical risk descriptors, their units and identifiers

Descriptors		Units
X_{RF1}	Damaged area	Percentage (damaged area / build area)
X_{RF2}	Dead people	Number of dead people each 1000 inhabitants
X_{RF3}	Injured people	Number of injured people each 1000 inhabitants
X_{RF4}	Ruptures in water mains	Number of ruptures / Km^2
X_{RF5}	Rupture in gas network	Number of ruptures / Km^2
X_{RF6}	Fallen lengths on HT power lines	Metres of fallen lengths / Km^2
X_{RF7}	Telephone exchanges affected	Vulnerability index
X_{RF8}	Electricity substations affected	Vulnerability index
X_{RF9}	Damage in the road network.	Damage index

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2. EXAMPLE OF APPLICATION: SEISMIC RISK OF BOGOTÁ

In Bogotá, the capital of Colombia, the localities are political-administrative subdivisions of the urban territory, with clear competences in financing and application of resources. They were created with the objective of attending in an effective way the necessities of the population of each territory. Since 1992, Bogotá has 20 localities which can be seen in Figure 6: Usaquén, Chapinero, Santafé, San Cristóbal, Usme, Tunjuelito, Bosa, Ciudad Kennedy, Fontibón, Engativa, Suba, Barrios Unidos, Teusaquillo, Mártires, Antonio Nariño, Puente Aranda, Candelaria, Rafael Uribe, Ciudad Bolívar y Sumapaz. In this study, only 19 of these localities are considered, because the locality of Sumapaz corresponds to the rural area.

As it is well known, the seismic hazard is the most significant threat for Bogotá. The scenario of seismic physical risk illustrated also in Figure 6 was used as a starting point for the application of the model. It displays the mean damaged area in predefined cells or zones considering a strong near field earthquake with 0.2g acceleration at the bedrock [Universidad de Los Andes, 1996].

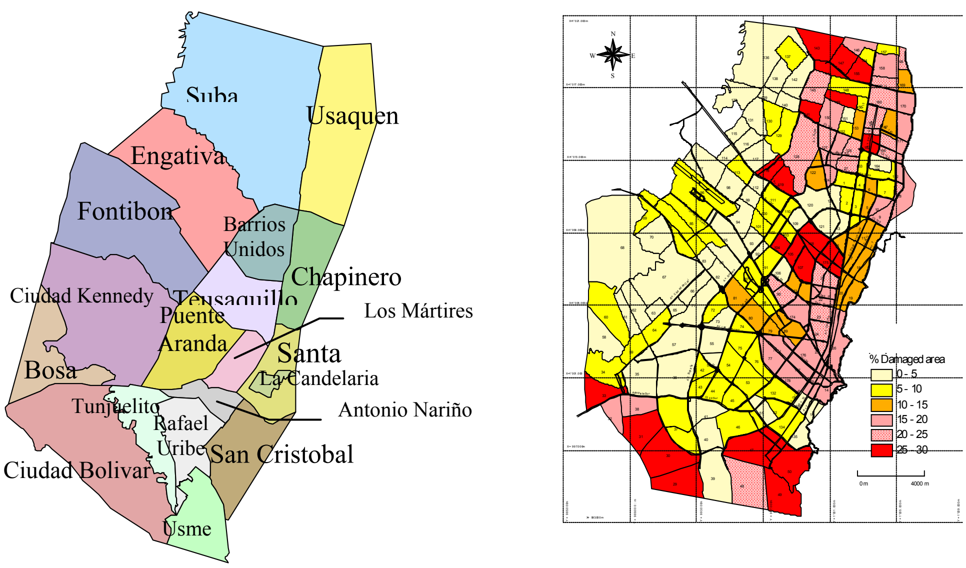

Figure 6. Political-administrative division of Bogotá, and scenario of physical seismic risk, Universidad de Los Andes (1996)

Tables 4 and 5 show the weights computed using the AHP, for the components of the physical risk and for the aggravating factors, respectively. The weights are calculated in Carreño et al. (2005).

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Table 4. Physical risk descriptors, their units and identifiers

Factor	Weight	Weight value
F_{RF1}	w_{RF1}	0.31
F_{RF2}	w_{RF2}	0.10
F_{RF3}	w_{RF3}	0.10
F_{RF4}	w_{RF4}	0.19
F_{RF5}	w_{RF5}	0.11
F_{RF6}	w_{RF6}	0.11
F_{RF7}	w_{RF7}	0.04
F_{RF8}	w_{RF8}	0.04

Table 5. Weights for the factors of the aggravating conditions

Factor	Weight	Weight value
F_{FS1}	w_{FS1}	0.18
F_{FS2}	w_{FS2}	0.04
F_{FS3}	w_{FS3}	0.04
F_{FS4}	w_{FS4}	0.18
F_{FS5}	w_{FS5}	0.18
F_{FR1}	w_{FR1}	0.06
F_{FR2}	w_{FR2}	0.06
F_{FR3}	w_{FR3}	0.04
F_{FR4}	w_{FR4}	0.03
F_{FR5}	w_{FR5}	0.09
F_{FR6}	w_{FR6}	0.09

Table 6. Descriptor values of the physical risk, R_F

Locality	X_{RF1}	X_{RF2}	X_{RF3}	X_{RF4}	X_{RF5}	X_{RF6}	X_{RF7}	X_{RF8}
Usaquen	15.1186	4	27	2	0	24	0.7	0.83
Chapinero	5.0302	5	27	5	0	81	0.77	0.9
Santafé	6.6070	3	16	7	0	63	0.62	0.9
San Cristóbal	4.9278	2	13	4	0	34	0.68	0.9
Usme	10.5870	0	1	1	1	14	0.67	0.9
Tunjuelito	3.5494	0	1	1	0	7	0.58	0.7
Bosa	4.2461	2	12	3	1	42	0.73	0.9
Ciudad Kennedy	4.8198	0	2	1	0	11	0.54	0.7
Fontibón	5.3163	1	7	1	0	5	0.64	0.7
Engativa	6.8777	1	5	1	0	3	0.66	0.8
Suba	13.8449	2	13	1	0	19	0.66	0.77
Barrios Unidos	12.2659	4	27	2	1	45	0.75	0.9
Teusaquillo	10.2985	8	41	4	0	36	0.74	0.9
Mártires	7.0283	6	30	2	0	18	0.66	0.7
Antonio Nariño	4.0287	0	2	2	0	17	0.67	0.8
Puente Aranda	5.7006	1	6	2	0	20	0.69	0.7
Candelaria	8.9515	9	44	6	0	81	0.67	0.9
Rafael Uribe	3.2433	1	11	2	0	29	0.65	0.9
Ciudad Bolívar	8.8908	1	11	1	1	21	0.64	0.9

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Tables 6 show the values of the descriptors used in this application, which represent the physical risk.

Table 7 shows the values of the factors of physical risk obtained by applying the functions of the Figure 4. The aggravating factors due to the social fragility and the lack of resilience are obtained by the applying the functions of figures 2 and 3.

Table 7. Factors, F_{RF}, and the physical risk index, R_F

Locality	F_{RF1}	F_{RF2}	F_{RF3}	F_{RF4}	F_{RF5}	F_{RF6}	F_{RF7}	F_{RF8}	R_F
Usaquen	0.881	0.0128	0.259	0.08	0	0.0288	0.7	0.83	0.386
Chapinero	0.127	0.02	0.259	0.5	0	0.328	0.77	0.9	0.264
Santafé	0.218	0.0072	0.091	0.82	0	0.198	0.62	0.9	0.314
San Cristobal	0.121	0.0032	0.0601	0.32	0	0.0578	0.68	0.9	0.175
Usme	0.557	0	0.00036	0.02	0.08	0.0098	0.67	0.9	0.253
Tunjuelito	0.063	0	0.00036	0.02	0	0.0025	0.58	0.7	0.076
Bosa	0.090	0.0032	0.0512	0.18	0.08	0.0882	0.73	0.9	0.152
Ciudad Kennedy	0.116	0	0.00142	0.02	0	0.0061	0.54	0.7	0.092
Fontibón	0.141	0.0008	0.0174	0.02	0	0.0012	0.64	0.7	0.105
Engativa	0.237	0.0008	0.00889	0.02	0	0.0004	0.66	0.8	0.139
Suba	0.811	0.0032	0.0601	0.02	0	0.0181	0.66	0.77	0.326
Barrios Unidos	0.701	0.0128	0.259	0.08	0.08	0.101	0.75	0.9	0.350
Teusaquillo	0.529	0.0512	0.589	0.32	0	0.0648	0.74	0.9	0.366
Mártires	0.247	0.0288	0.32	0.08	0	0.0162	0.66	0.7	0.186
Antonio Nariño	0.081	0	0.00142	0.08	0	0.145	0.67	0.8	0.116
Puente Aranda	0.162	0.0008	0.0128	0.08	0	0.02	0.69	0.7	0.126
Candelaria	0.401	0.0648	0.658	0.68	0	0.328	0.67	0.9	0.426
Rafael Uribe	0.0526	0.0008	0.043	0.08	0	0.042	0.65	0.9	0.103
Ciudad Bolívar	0.395	0.0008	0.043	0.02	0.08	0.022	0.64	0.9	0.206
Bogotá	*0.41*	*0.0039*	*0.0536*	*0.092*	*0.04*	*0.0379*	*0.664*	*0.8630*	*0.2246*

Table 8 shows the results for the physical risk, the impact factor and the total risk of each locality and the average values for the city.

Figures 7 to 11 display graphically the results of the holistic evaluation of the seismic risk of Bogotá using the proposed model. These figures show that the locality of Candelaria has the most critical situation from the point of view of the physical and total seismic risk, because its impact factor is significant, although it is not the highest of the city.

The localities with greater impact factor are Usme, San Cristóbal, Bosa and Ciudad Bolivar, whereas the lowest values are those of Barrios Unidos, Chapinero and Teusaquillo. High values of the greater physical risk index, in addition to Candelaria, are the localities of Usaquén, Barrios Unidos and Teusaquillo, whereas the physical risk index is less in Ciudad Kennedy and Tunjuelito. The greater values of total risk index appear in the localities of Candelaria, Usaquen, Santafé

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and Barrios Unidos, and the smaller values are those of Ciudad Kennedy, Fontibón and Tunjuelito.

Table 8. Total risk of Bogotá

Locality	R_F	F	R_T
Usaquen	0.386	0.309	0.505
Chapinero	0.264	0.245	0.329
Santafé	0.314	0.478	0.464
San Cristóbal	0.175	0.707	0.298
Usme	0.253	0.797	0.454
Tunjuelito	0.076	0.587	0.121
Bosa	0.152	0.701	0.258
Ciudad Kennedy	0.092	0.643	0.150
Fontibón	0.105	0.358	0.142
Engativa	0.139	0.521	0.211
Suba	0.326	0.369	0.446
Barrios Unidos	0.350	0.302	0.456
Teusaquillo	0.366	0.193	0.436
Mártires	0.186	0.325	0.246
Antonio Nariño	0.116	0.407	0.163
Puente Aranda	0.126	0.391	0.175
Candelaria	0.426	0.631	0.694
Rafael Uribe	0.103	0.635	0.169
Ciudad Bolivar	0.206	0.700	0.350
Bogotá	*0.225*	*0.663*	*0.374*

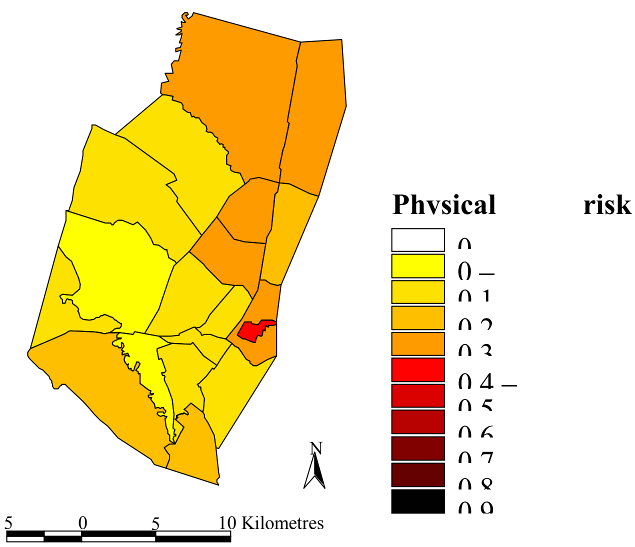

Figure 7. Physical risk index, R_F, for the localities of Bogotá

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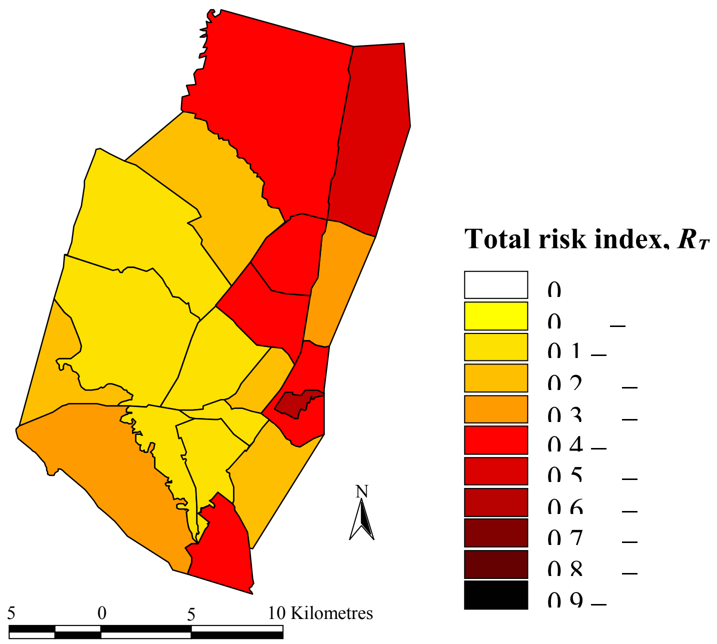

Figure 8. Total risk index, R_T, for the localities of Bogotá

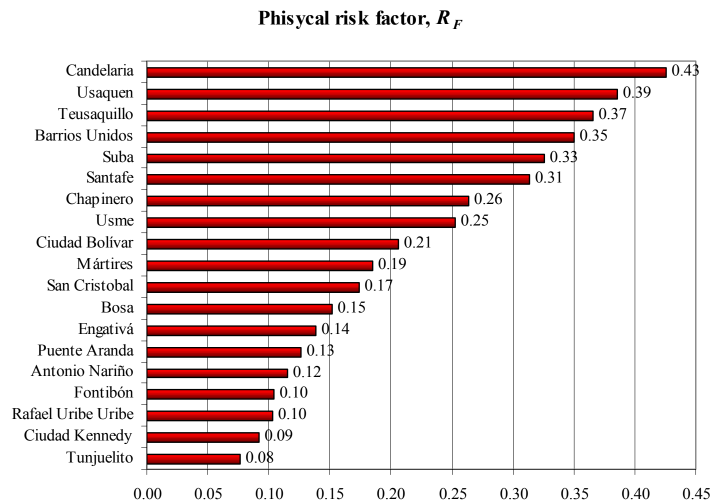

Figure 9. Physical risk index for the localities of Bogotá, in descendent order

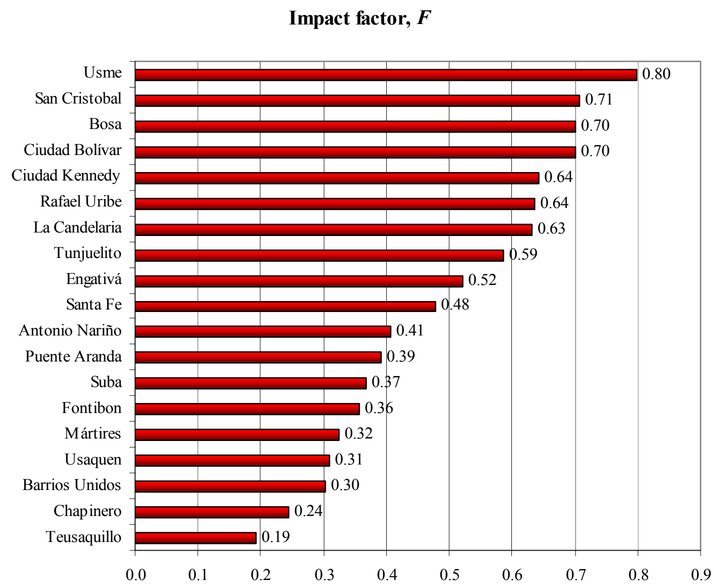

Figure 10. Impact factor for the localities of Bogotá, in descendent order

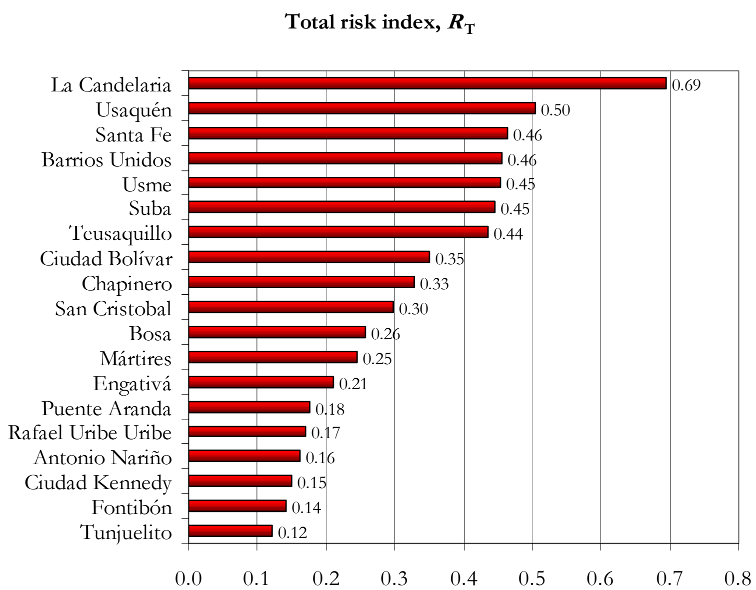

Figure 11. Total risk index for the localities of Bogotá, in descendent order

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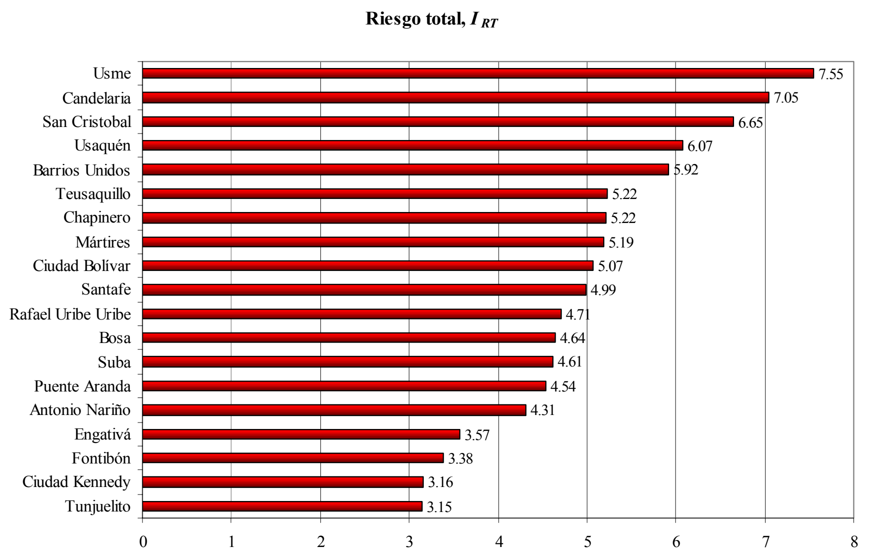

Figure 12. Total risk index for the localities of Bogotá, obtained with the Cardona's model

3. EXAMPLE OF APPLICATION: SEISMIC RISK OF BARCELONA

The city of Barcelona, Spain, is subdivided in ten districts (see Figure 13), which are directed by a Mayor. The districts have management competences in subjects like urbanism, public space, infrastructure maintenance, etc. They are: Ciutat Vella, Eixample, Sants-Montjuïc, Les Corts, Sarrià-Sant Gervasi, Gràcia, Horta-Guinardó, Nou Barris, Sant Andreu and Sant Martí.

The districts are subdivided in 38 neighbourhoods or large statistical zones. Barcelona is also subdivided in 248 small statistical zones (ZRP). The physical risk index was calculated from a probabilistic risk scenario developed in the framework of the Risk-UE project [ICC/CIMNE, 2004]. This scenario was calculated considering the 248 small ZRP zones. The impact factor was calculated by district, due to the availability of data at this level only.

Figures 14 to 16 show the results for the physical risk index, the impact factor and the total risk index for Barcelona using the model proposed above. Details about the calculation can be seen in Carreño et al. (2005, 2006).

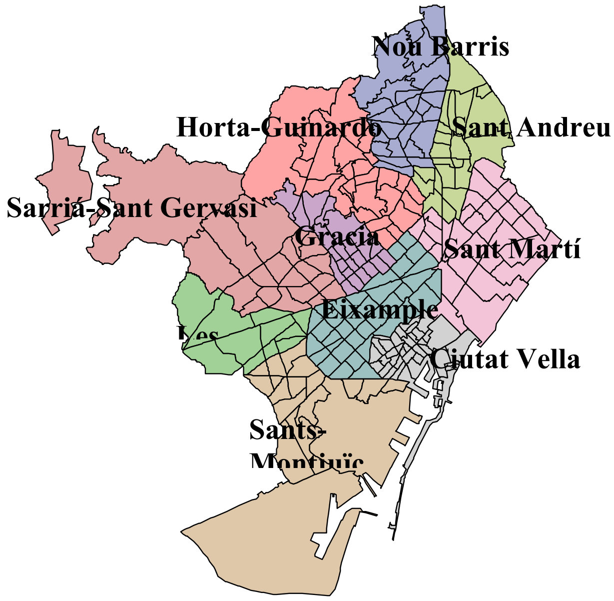

Figure 13. Territorial division of Barcelona

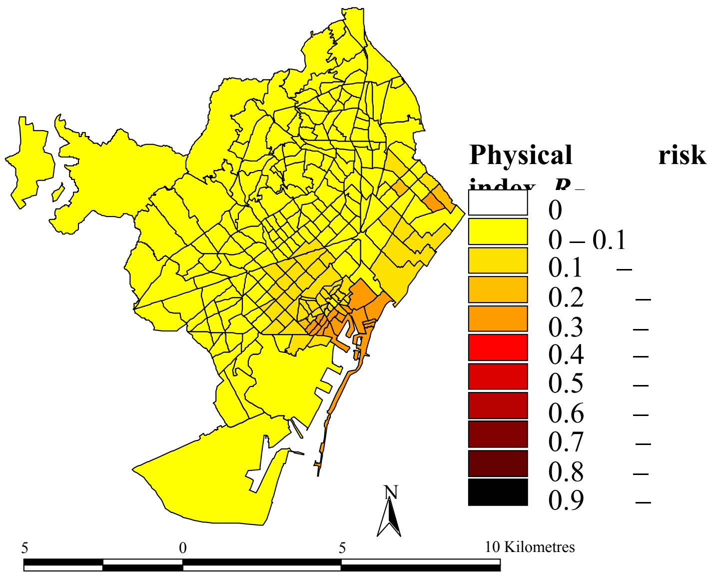

Figure 14. Physical risk index for Barcelona, using the 248 small statistical zones (ZRP)

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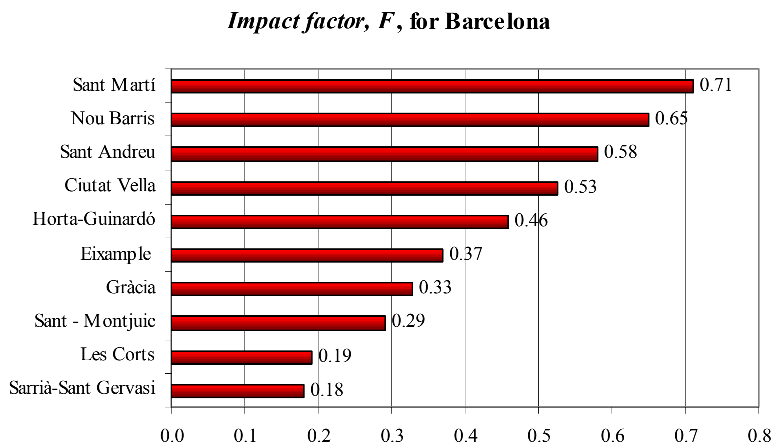

Figure 15. Impact factor for the districts of Barcelona

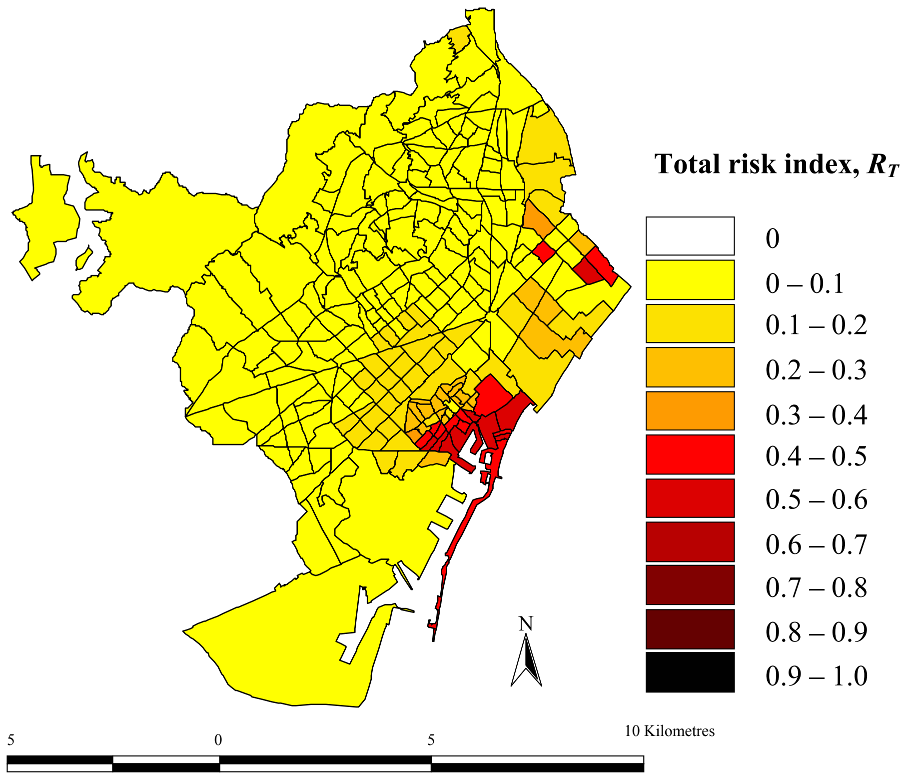

Figure 16. Total risk index for Barcelona, using the 248 small statistical zones (ZRP)

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5. CONCLUSIONS

Risk estimation requires a multidisciplinary approach that takes into account not only the expected physical damage, the number and type of casualties or economic losses, but also other social, organizational and institutional factors related to the development of communities that contribute to the creation of risk. At the urban level, for example, vulnerability seen as an internal risk factor should be related not only to the level of exposure or the physical susceptibility of the buildings and infrastructure material elements potentially affected, but also to the social fragility and the lack of resilience of the exposed community.

The absence of institutional and community organization, weak preparedness for emergency response, political instability and the lack of economic health in a geographical area contribute to increased risk increasing. Therefore, the potential negative consequences are not only related to the impact of the hazardous event as such, but also to the capacity to absorb the impact and the control of its implications in a given geographical area.

For the modelling, a simplified but multidisciplinary representation of urban seismic risk has been suggested, based on the parametric use of variables that reflect aspects or factors of such risk. This parametric approach is not more than a model formulated in the most realistic possible form, to which corrections or alternative figures may be continuously introduced. The consideration of physical aspects allowed the construction of a physical risk index. Also, the contextual variables (social, economic, etc.) allowed the construction of an impact factor. The former is built from the information about the seismic scenarios of physical damage (direct effects) and the latter is the result from the estimation of aggravating conditions (indirect effects) based on descriptors and factors related to the social fragility and the lack of resilience of the exposed elements.

This new model for holistic evaluation of risk facilitates the integrated risk management by the different stakeholders involved on risk reduction decision-making. It permits the follow-up of the risk situation and the effectiveness and efficiency of the prevention and mitigation measures can be easily achieved. Results can be verified and the mitigation priorities can be established as regards the prevention and planning actions to modify those conditions having a greater influence on risk in the city.

Once the results have been expressed in graphs for each locality or district, it is easy to identify the most relevant aspects of the total risk index, with no need for further analysis and interpretation of results. Finally, this method allows to compare risk among different cities around the world and to perform a multi-hazard risk analysis.

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