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Urban Seismic Risk Evaluation: A Holistic Approach

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Abstract. 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, which favour the second order effects (indirect effects) when a hazard event strikes an urban centre. The proposed general method of urban risk evaluation is multi hazard and holistic, that is, an integrated and comprehensive approach to guide decision-making. The evaluation of the potential physical damage (hard approach) as the result of the convolution of hazard and physical vulnerability of buildings and infrastructure is the first step of this method. Subsequently, a set of social context conditions that aggravate the physical effects are also considered (soft approach). 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 or aggravating coefficient, based on variables associated with the socio-economic conditions of each unit of analysis. Finally, the proposed method is applied in its single hazard form to the holistic seismic risk evaluation for the cities of Bogota (Colombia) and Barcelona (Spain).

Key words: holistic approach, risk evaluation, seismic risk, socio-economic vulnerability

1. The Notion of Risk

Many of the conceptual approaches of risk had their origin in the studies on technological hazards and some of them were extrapolated to the field of natural disaster risk. Perhaps, the first specialized researches on the topic of natural disasters started in the early 1960's based on the pioneering contributions of Gilbert White (1964) from the view of the ecology and

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geography. Sociologists as Enrico Quarantelli (1988) and Dynes and Drabek (1994) since 1963 devoted efforts to explain the social response to disasters following analogies with response in case of nuclear attacks. Geographers as Robert Kates (1971) and Roger Kasperson et al. (1988) and physicist Christopher Hohenemser focused their research in both natural and nuclear risks. The point of view of civil engineering has been materialized in the developments performed in the field of physical risk. Thus, starting from the work on damage assessment of Whitman (1973), innumerable methodologies devoted to the physical seismic risk assessment have been developed all over the world. Later, this process evolved towards a more integrated vision of the seismic risk, incorporating others of its aspects (Coburn and Spence 1992) until reaching the widespreaded HAZUS (FEMA, 1999) methodology, now available for multi hazard risk assessment. During the 1990's, stimulated by the International Decade for Natural Disaster Reduction, IDNDR, many researches dealing with risks and disasters were developed around the world. The topic gained importance and it is being increasingly recognized that the terms hazard, vulnerability and risk have had different meanings and implications from both the methodological and practical angles (Cardona, 2004).

An example of a systemic model of risk was provided by Kates (1971) from the ecologic school of thought. He describes the notion of 'adjustment' to natural hazards considering the interactions between nature, humans and technology. Palmlund (1989) proposed a model analogue with the classic structure of a Greek tragedy (with actors, scenario, drama, and roles) in order to explain the environmental disaster from a political and social perspective. A classic contextual or structural explanation, where risk is seen as an attribute of social structures, is that proposed by Douglas and Wildavsky (1982). A cultural theory of risk is proposed by Rayner (1992) while approaches of the Political Economy school are given by Westgate and O'Keefe (1976), Wijkman and Timberlake (1984), Susman *et al.* (1984) and Chambers (1989). The contributions of Wisner (1993), Cannon (1994), Blaikie *et al.* (1996) and of members of the Network for the Social Study of Disaster Prevention in Latin America (La Red) (Maskrey, 1994; Lavell, 1996; Cardona, 1996; Mansilla, 1996) may also be considered constructivist, emphasizing the social construction of vulnerability and risk. One of the conceptual contributions that derived in a multidisciplinary approach was made by Wilches-Chaux (1989). He proposed different classes of vulnerabilities (cultural, environmental, social, economic, physical, etc.).

The report *Natural Disasters and Vulnerability Analysis* (UNDRO, 1980), based on the Expert Meeting held in 1979, 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,

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

Based on this formulation several methodologies for risk assessment have been developed from different perspectives in the last decades, and recently a holistic or multidisciplinary approach for the case of urban centres (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 localities (units) 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.

2. Methodology of Evaluation

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 proposed method is developed for a multi-hazard evaluation and therefore it is necessary to dispose of physical damage estimations for all the significant hazards. Often, when historical information is available, the principal hazard can be usually identified and thus the most potential critical situation.

The holistic evaluation of risk by means of indices is achieved affecting the physical risk with an impact factor, 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 Bogota, 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 of the alternative model.

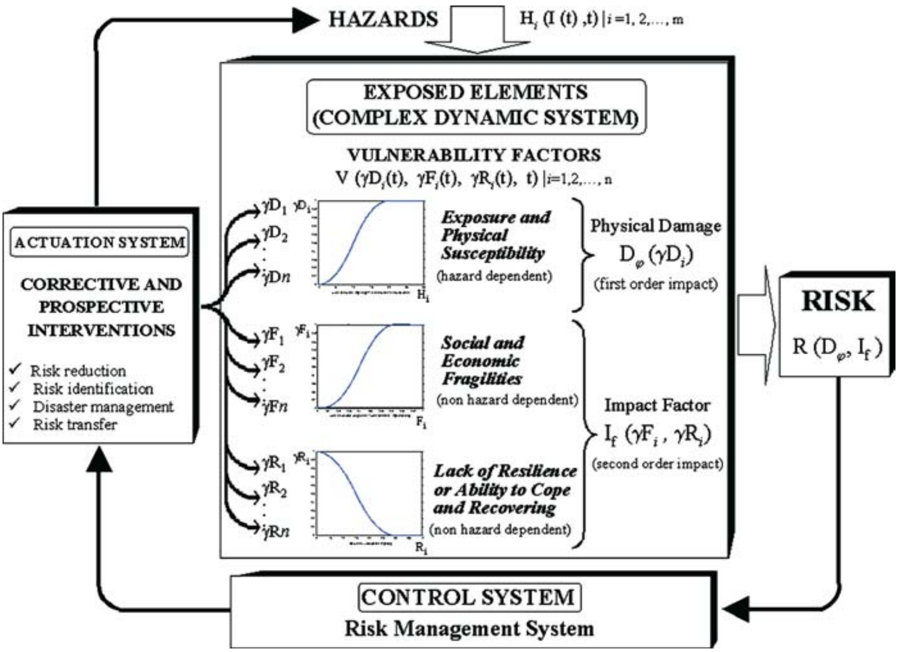

Figure 1. Theoretical framework and model for holistic approach of disaster risk (adapted from Cardona and Barbat, 2000).

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 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, which will be discussed later, are obtained from the loss scenarios and from socio-economic and coping capacity information of the exposed context (Carreño *et al.* 2005).

The model of holistic urban risk evaluation proposed in this paper improves conceptual and methodological aspects of the first proposal of Cardona (2001), 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 and giving more transparency and applicability in some cases. Cardona's model allows the evaluation of the seismic risk in an urban center taking into account the characteristics of the physical risk, seismic hazard, physical exposure, socio-economical fragility and lack of resilience, what permits to identify those characteristics of the city that increase the level of risk and also the critical areas. This model studies different types of information by means of indicators and uses a normalization process of the results based on the mean and on the standard deviation which is applied to each indicator. As a consequence, the results obtained with Cardona's method allow a comparison of the holistic seismic risk among the different areas of a city in a relative way, but not a comparison in absolute terms with other urban areas. Cardona's model uses of a neuro-fuzzy system, with fuzzy sets which identify the linguistic qualifications of the descriptors, but the necessary information for the calibration of this system do not exist.

The new method proposed in this article conserves the approach based on indicators, but it improves the procedure of normalization and calculates the final indices in an absolute (non relative) manner. This feature facilitates the comparison of risk among urban centers. The exposure and the seismic hazard have been eliminated in the method proposed in this paper because they have been included into the physical risk variables calculation. The descriptor of population density, a component of the exposure in Cardona's model is now included as a descriptor of social fragility. The new approach preserves the use of indicators and fuzzy sets or membership functions, proposed originally by Cardona, but in a different way. Other improvements of the proposed model refer to the units of some of the descriptors; in certain cases it is more important to normalize the input values respecting the population than with respect of the area of the studied zone. This is, for example, the case of the number of hospital beds existing in the studied urban area.

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 direct effect, or physical risk, and the indirect effects expressed as a factor of the direct effects. Therefore, the total risk can be expressed as follows:

$$R_{\mathrm{T}} = R_{\mathrm{F}}(1 + F) \tag{2}$$

expression known as the Moncho's Equation in the field of disaster risk indicators, where 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}

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

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.

The aggravating factors F_{FSi} and F_{FRj} are calculated using transformation functions shown in the Figures 2 and 3. These functions standardise 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), which is used to derive ratio scales from both discrete and continuous paired comparisons (Saaty, 2001). This process, completely

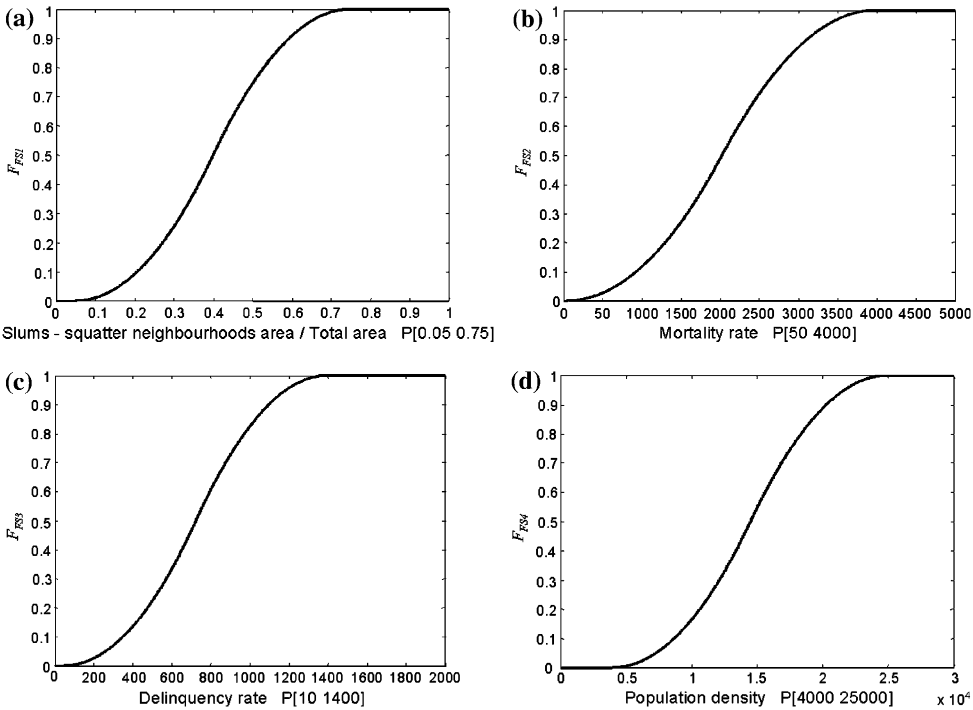

Figure 2. Transformation functions used to standardise the social fragility factors.

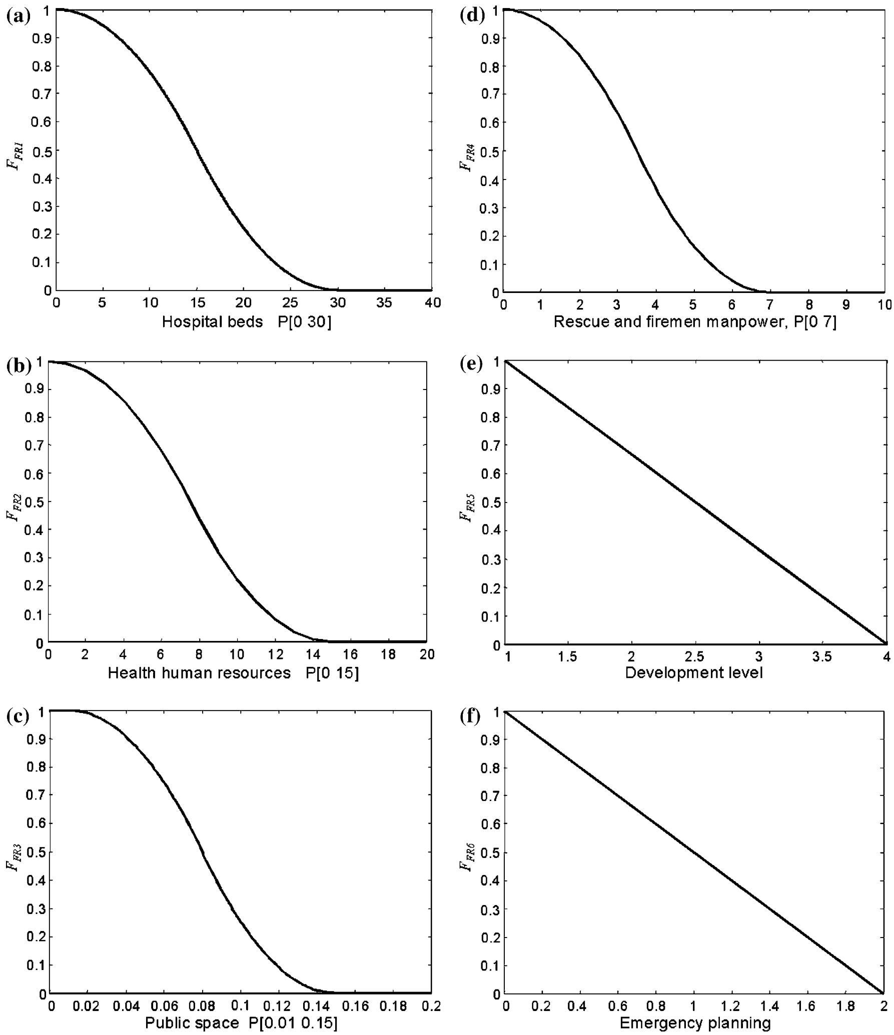

Figure 3. Transformation functions used to standardise the lack of resilience factors.

explained in the Appendix, has been performed starting from the experts opinions collected in Tables A.1 and A.3 by means of the Delphi method. This is the most adequate way of judging the relative importance of variables having different nature and calculating their relative weights.

The physical risk, R_F, is evaluated in the same way, using the transformation functions shown in the Figure 4.

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

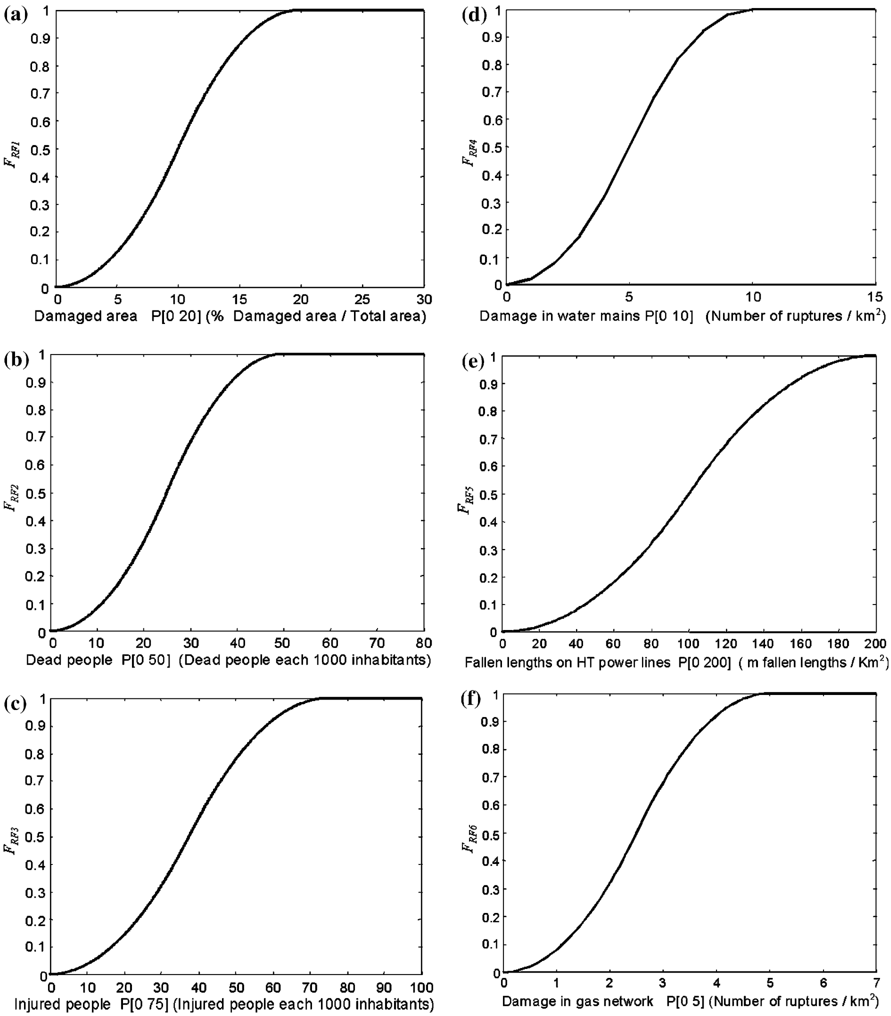

Figure 4. Transformation functions used to standardise the physical risk factors.

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. It has to be mentioned that the calculation of physical risk scenarios is not the objective of the methodology developed in this paper, but the physical risk index is obtained starting from existing loss evaluations.

It is estimated that the indirect effects of hazard events, sized by the factor F in Equation (2), can be of the same order than the direct effects. According to the Economic Commission for Latin America and the Caribbean (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_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 in most of the cases (see Figures 2–4). There are two exceptions in the case of the lack of resilience, the descriptors of the level of development of the community and of the emergency planning or preparedness, for which a linear relation was assumed. Once decided the shape of these functions, all their maximum and minimum values (corresponding to the values 1 or 0 of each factor) were fixed using existing information about past disasters as well as the opinion of American and European experts. Table I gives the variables used to describe the social fragility and the lack of resilience in the estimation of the impact factor F. The transformation functions describe the intensity of the risk for each descriptor. For example, the transformation function for the mortality rate, defined as the number of deaths by natural causes for each 10,000 inhabitants, suggest that the aggravation for this factor is minimal if it takes a value smaller than 50 deaths for each 10,000 inhabitants, and the aggravation is maximal if the value is bigger than 4,000 deaths for each 10,000 inhabitants. Another example is the case of the damaged built area; the corresponding

Table I. 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

transformation function defines a minimum risk (0) when this descriptor is zero and, the maximum risk (1) was established for a potential damaged area of 20% of the constructed one according to the experts opinion.

Figures 2–4 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 II presents the initial measurement units of each descriptor of social fragility and resilience. Table III 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

Table II. 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 10,000 inhabitants
X_{FS3}	Delinquency rate	Number of crimes each 100,000 inhabitants
X_{FS4}	Social disparity index	Index between 0 and 1
X_{FS5}	Population density	Inhabitants/Km^2 of build area
X_{FR1}	Hospital beds	Number of hospital beds each 1,000 inhabitants
X_{FR2}	Health human resources	Health human resources each 1,000 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}	Risk management index	Index between 0 and 1*

* This index is defined by Carreño et al. (2005).

Table III. Physical risk descriptors, their units and identifiers.

Descriptor		Units
X_{RF1}	Damaged area	Percentage (damaged area/build area)
X_{RF2}	Dead people	Number of dead people each 1,000 inhabitants
X_{RF3}	Injured people	Number of injured people each 1,000 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

with the units of tables above-mentioned. Figure 5 shows the process of calculation of the total risk index for the units of analysis, which could be districts, municipalities, communes or localities.

3. Examples of Application

3.1. SEISMIC RISK OF BOGOTA

In Bogota, the capital of Colombia, the localities or mayorships 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 needs of the population of each territory. Since 1992, Bogota 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 and Sumapaz. In this study, only 19 of these

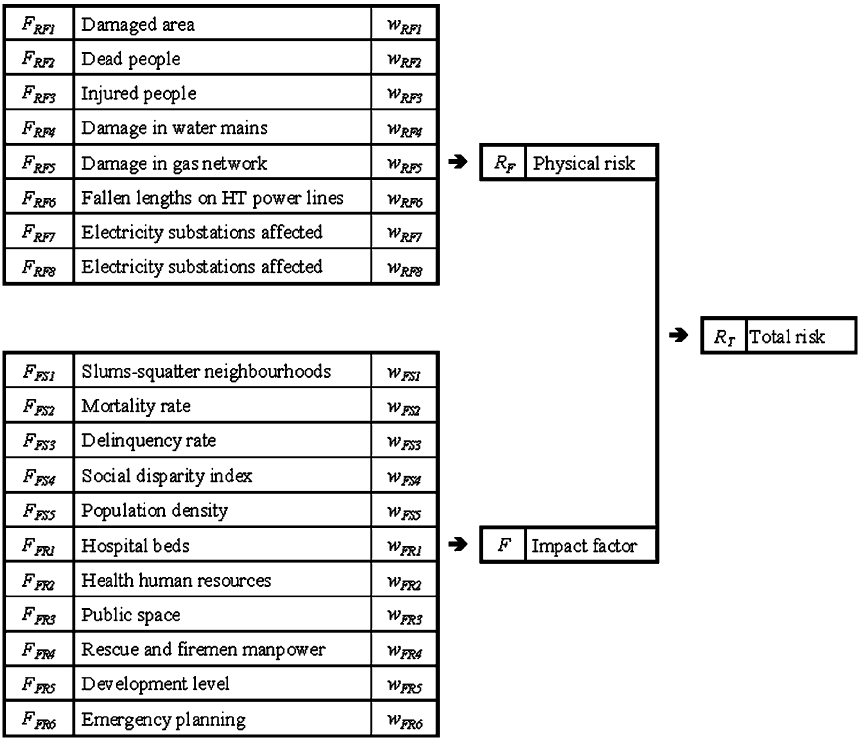

Figure 5. Factors of physical risk, social fragility and lack of resilience and their weights.

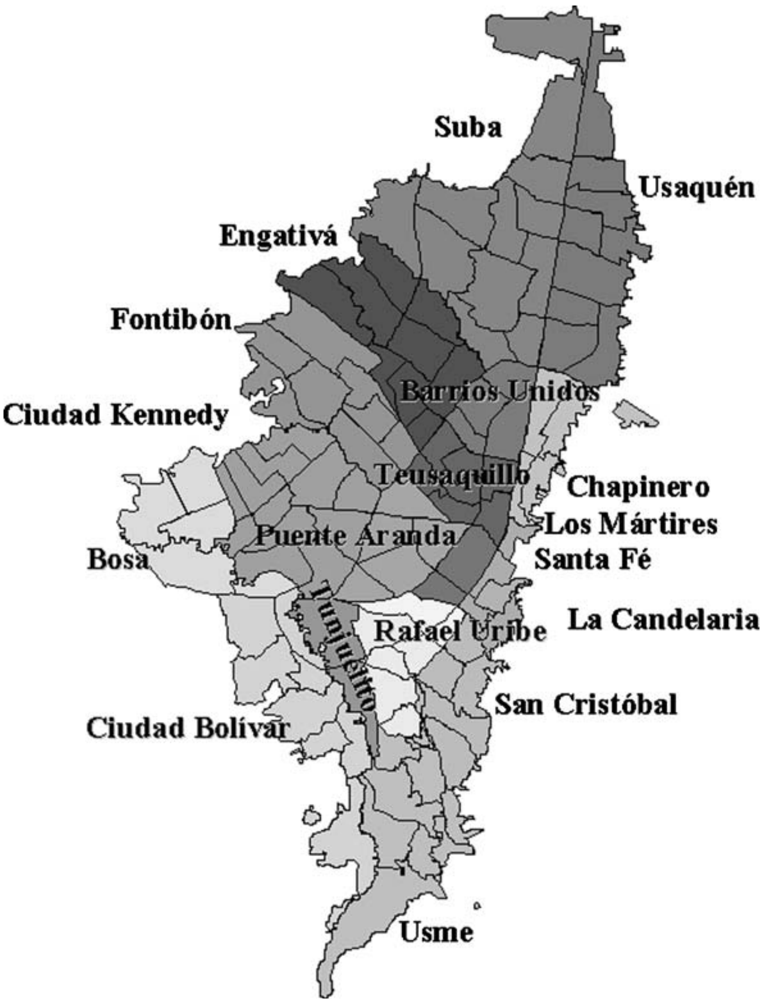

Figure 6. Political-administrative division of Bogota, Colombia.

localities are considered, because the locality of Sumapaz corresponds to the rural area. These localities are subdivided in 117 territorial units (UPZ).

As it is well known, the seismic hazard is the most significant threat for Bogota. The scenario of seismic physical risk illustrated in Figure 7 (Universidad de Los Andes, 2005) was used as a starting point for the application of the model. It displays the percentage of the damaged area in predefined cells considering that an earthquake with a magnitude Ms of 7.4 and a return period of 500 years occurs in the frontal fault of the Western Mountains (Universidad de Los Andes, 2005). The seismic risk scenario was calculated by means of building by building simulations and,

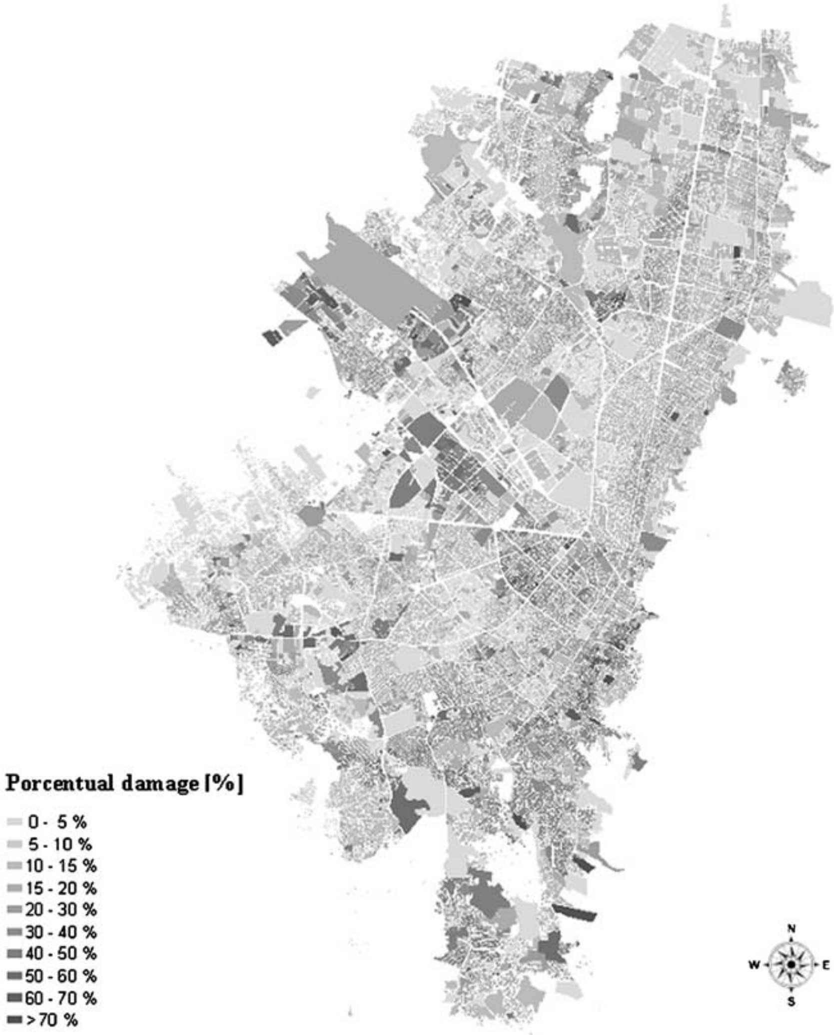

Figure 7. One scenario of physical seismic risk (Universidad de los Andes, 2005).

thus, the descriptors of the physical risk can be obtained for each UPZ. Nevertheless, the information regarding the aggravating factors has been calculated for each locality and not for each UPZ, as it will be seen later.

Tables IV and V show the weights computed using the AHP, as it is described in the Appendix, for the components of the physical risk and for the aggravating factors, respectively.

Tables VI and VIII show the values of the descriptors used in this application, which represent the physical risk and the social fragility and the lack of resilience of the city, respectively. Table VII shows the values

Table IV. Weights for the factors of the physical risk.

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 V. 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

of the factors of physical risk obtained by applying the functions of the Figure 4. Table IX shows the aggravating factors of the indirect effects due to the social fragility and the lack of resilience; they are obtained by the applying the functions of Figures 2 and 3. The physical risk index, R_F, and the impact factor, F, are also indicated in these tables. In addition, the average values for the city are shown. They have been calculated normalizing by the density of population. Table X 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 8–12 display graphically the results of the holistic evaluation of the seismic risk of Bogota using the proposed model. The average values of the physical risk and total risk by locality are shown in Figures 10 and 12. These figures show that the locality of Candelaria has the most critical situation from the point of view of the physical and

Table VI. Descriptor values of the physical risk, R_F.

UPZ	Nombre UPZ	Localidad	X_{RF1}	X_{RF2}	X_{RF3}	X_{RF4}	X_{RF5}	X_{RF6}	X_{RF7}	X_{RF8}
1	Paseo los Libertadores	San Cristóbal	8.5	0	0	0.96	0.17	33.69	0.68	0.90
2	La Academia	Suba	5.6	0	1	0.81	0.17	19.14	0.66	0.77
3	Guaymaral	Suba	5.7	1	5	0.93	0.18	19.14	0.66	0.77
9	Verbenal	Usaquén	8.4	1	3	0.65	0.16	23.87	0.7	0.83
10	La Uribe	Usaquén	12.6	1	4	0.85	0.16	23.87	0.7	0.83
11	San Cristóbal Norte	Usaquén	12.3	1	4	0.67	0.14	23.87	0.7	0.83
12	Toberin	Usaquén	13	6	19	1.08	0.23	23.87	0.7	0.83
13	Los Cedros	Usaquén	12.8	8	17	0.83	0.20	23.87	0.7	0.83
...	...	...	...	...	...	...	...	...	...	...
110	Ciudad Salitre Occidental	Fontibón	10	11	21	0.89	0.16	5.49	0.64	0.7
111	Puente Aranda	Puente Aranda	21.6	55	181	1.11	0.27	20.19	0.69	0.7
112	Granjas Techo	Fontibón	30.4	102	337	0.94	0.22	5.49	0.64	0.7
113	Bavaria	Kennedy	15.5	22	57	1.14	0.24	10.80	0.54	0.7
114	Modelia	Fontibón	11.7	2	7	1.12	0.29	5.49	0.64	0.7
115	Capellania	Fontibón	27.2	23	74	1.24	0.31	5.49	0.64	0.7
116	Alamos	Negativa	36.3	21	63	1.23	0.33	2.82	0.66	0.8
117	Aeropuerto El Dorado	Fontibón	16.4	2	6	1.27	0.34	5.49	0.64	0.7

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

UPZ	Nombre UPZ	Localidad	F_{RF1}	F_{RF2}	F_{RF3}	F_{RF4}	F_{RF5}	F_{RF6}	F_{RF7}	F_{RF8}	R_F
1	Paseo los Libertadores	SanCristóbal	0.361	0	0	0.019	0.00243	0.058	0.68	0.9	0.188
2	La Academia	Suba	0.157	0	0.000356	0.0143	0.0024	0.0181	0.66	0.77	0.113
3	Guaymaral	Suba	0.162	0.0008	0.00889	0.018	0.00249	0.0181	0.66	0.77	0.116
9	Verbenal	Usaquén	0.353	0.0008	0.0032	0.00985	0.00201	0.0288	0.7	0.83	0.179
10	La Uribe	Usaquén	0.726	0.0008	0.00569	0.0157	0.00209	0.0288	0.7	0.83	0.298
11	San Cristóbal Norte	Usaquén	0.704	0.0008	0.00569	0.0105	0.00158	0.0288	0.7	0.83	0.290
12	Toberin	Usaquén	0.755	0.0288	0.128	0.0229	0.00414	0.0288	0.7	0.83	0.324
13	Los Cedros	Usaquén	0.741	0.0512	0.103	0.0148	0.00332	0.0288	0.7	0.83	0.318
...	...	...	...	...	...	...	...		...	...	...
110	Ciudad Salitre Occital.	Fontibón	0.5	0.0968	0.157	0.0168	0.00215	0.00125	0.64	0.7	0.242
111	Puente Aranda	Pte.Aranda	1	1	1	0.0239	0.00571	0.02	0.69	0.7	0.584
112	Granjas Techo	Fontibón	1	1	1	0.0182	0.00371	0.00125	0.64	0.7	0.579
113	Bavaria	Kennedy	0.899	0.387	0.885	0.0252	0.00444	0.00605	0.54	0.7	0.470
114	Modelia	Fontibón	0.656	0.0032	0.0174	0.0182	0.00655	0.00125	0.64	0.7	0.268
115	Capellania	Fontibón	1	0.423	1	0.0297	0.00788	0.00125	0.64	0.7	0.522
116	Álamos	Engativá	1	0.353	0.949	0.0292	0.00886	0.00045	0.66	0.8	0.515
117	Aeropuerto El Dorado	Fontibón	0.935	0.0032	0.0128	0.031	0.00902	0.00125	0.64	0.7	0.358

Table VIII. Values of aggravating descriptors for social fragility and lack of resilience factors of Bogota.

Locality	X_{FS1}	X_{FS2}	X_{FS3}	X_{FS4}	X_{FS5}	X_{FR1}	X_{FR2}	X_{FR3}	X_{FR4}	X_{FR5}	X_{FR6}
Antonio Nariño	0.015	398	120	0.2	28338	4.871	5	0.016	13	2	0.0456
Barrios Unidos	0.002	917	130	0.29	25920	1.254	33	0.150	9	2	0.0456
Bosa	0.249	1366	92	0.51	44458	0.338	3	0.038	4	2	0.0702
Chapinero	0.131	612	249	0	9255	16.265	89	0.032	19	3	0.0724
Ciudad Bolívar	0.239	1866	78	0.92	48968	0.503	3	0.035	7	2	0.1884
Engativa	0.061	2747	53	0.41	34958	0.183	7	0.142	11	2	0.1715
Fontibon	0.129	1028	34	0.39	37558	0.206	4	0.109	2	2	0.0456
Kennedy	0.164	2546	68	0.44	41451	0.756	8	0.084	1	1	0.0456
La Candelaria	0.248	100	86	0.34	13074	2.509	0	0.000	13	1	0.0456
Los Mártires	0.036	621	84	0.33	32227	2.846	103	0.033	48	2	0.0596
Puente Aranda	0.001	1323	32	0.37	37211	0.616	4	0.062	8	2	0.1715
Rafael Uribe	0.237	1618	109	0.5	36759	1.605	11	0.084	6	1	0.1715
San Cristobal	0.265	1648	55	0.82	41875	3.490	19	0.108	11	1	0.3383
Santa Fe	0.771	694	182	0.36	17764	6.176	143	0.150	46	1	0.0904
Suba	0.110	2621	115	0.41	25886	1.181	15	0.045	4	2	0.177
Teusaquillo	0.002	681	90	0.05	14437	5.556	20	0.112	8	3	0.1315
Tunjuelito	0.161	941	63	0.45	37702	2.540	13	0.084	9	1	0.0552
Usaquen	0.050	1473	74	0.33	20836	3.972	28	0.129	3	2	0.0456
Usme	0.168	850	129	1	32863	0.199	2	0.021	12	2	0.0456

Table IX. Impact factor, F, computed with aggravating factors of social fragility and lack of resilience.

Localidad	F_{FS1}	F_{FS2}	F_{FS3}	F_{FS4}	F_{FS5}	F_{FR1}	F_{FR2}	F_{FR3}	F_{FR4}	F_{FR5}	F_{FR6}	F
Antonio Nariño	0	0.0155	0.00538	0.2	1	0.947	0.778	0.996	0	0.6	0.95	0.50
Barrios Unidos	0	0.0964	0.00702	0.29	1	0.997	0	0	0	0.6	0.95	0.44
Bosa	0.162	0.222	0.00194	0.51	1	1	0.92	0.92	0.367	0.6	0.93	0.61
Chapinero	0.0268	0.0405	0.0435	0	0.125	0.419	0	0.951	0	0.3	0.93	0.20
Ciudad Bolívar	0.146	0.423	0.00086	0.92	1	0.999	0.92	0.936	0	0.6	0.81	0.67
Engativa	0.000494	0.799	0.00000988	0.41	1	1	0.564	0.00653	0	0.6	0.83	0.51
Fontibon	0.0255	0.123	0	0.39	1	1	0.858	0.172	0.837	0.6	0.95	0.55
Kennedy	0.053	0.729	0.000356	0.44	1	0.99	0.436	0.444	0.959	1	0.95	0.62
La Candelaria	0.16	0.00032	0.00142	0.34	0.373	0.986	1	1	0	1	0.95	0.49
Los Mártires	0	0.0418	0.00127	0.33	1	0.982	0	0.946	0	0.6	0.94	0.48
Puente Aranda	0	0.208	0	0.37	1	0.999	0.858	0.724	0	0.6	0.83	0.52
Rafael Uribe	0.143	0.315	0.00382	0.5	1	0.994	0.142	0.444	0.0408	1	0.83	0.56
San Cristobal	0.189	0.327	0.0000274	0.82	1	0.973	0	0.18	0	1	0.66	0.59
Santa Fe	1	0.0532	0.0191	0.36	0.763	0.915	0	0	0	1	0.91	0.61
Suba	0.0147	0.756	0.00464	0.41	1	0.997	0	0.875	0.367	0.6	0.82	0.52
Teusaquillo	0	0.051	0.00176	0.05	0.494	0.931	0	0.147	0	0.3	0.87	0.27
Tunjuelito	0.0503	0.102	0.000185	0.45	1	0.986	0.0356	0.444	0	1	0.94	0.53
Usaquen	0	0.26	0.000632	0.33	0.921	0.965	0	0.045	0.633	0.6	0.95	0.46
Usme	0.0568	0.082	0.00685	1	1	1	0.964	0.988	0	0.6	0.95	0.67

Table X. Seismic risk of Bogota.

Locality	R_F	F	R_T
Antonio Nariño	0.41	0.50	0.62
Barrios Unidos	0.27	0.44	0.38
Bosa	0.18	0.61	0.28
Chapinero	0.47	0.20	0.57
Ciudad Bolívar	0.39	0.75	0.65
Engativa	0.36	0.51	0.54
Fontibon	0.41	0.55	0.64
Kennedy	0.24	0.62	0.38
La Candelaria	0.62	0.49	0.93
Los Mártires	0.47	0.48	0.69
Puente Aranda	0.43	0.52	0.65
Rafael Uribe	0.39	0.56	0.61
San Cristobal	0.37	0.59	0.58
Santa Fe	0.48	0.61	0.77
Suba	0.25	0.52	0.38
Teusaquillo	0.40	0.27	0.51
Tunjuelito	0.39	0.53	0.60
Usaquen	0.30	0.46	0.44
Usme	0.37	0.67	0.62
Bogota	0.32	0.55	0.50

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, Ciudad Bolivar, Ciudad Kennedy and Bosa, whereas the lowest values are those of Barrios Unidos, Teusaquillo and Chapinero. High values of the greater physical risk index, in addition to Candelaria, are the localities of Santa Fe, Chapinero and Los Martires, whereas the physical risk index is less in Ciudad Kennedy and Bosa. The greater values of total risk index appear in the localities of Candelaria, Santafé and Los Martires, and the smaller values are those of Ciudad Kennedy, Barrios Unidos and Bosa.

Bogota was previously studied using the earlier model. Figure 13 shows the obtained results (Cardona, 2001). This was the first integrated analysis of the seismic risk of the city. The results obtained with that model only allow ordering the localities in function of their relative total risk. Although the index values are different, the ranking using both models is similar. For example, the locality of Tunjuelito has the smallest total risk and the locality of Candelaria has the greatest total risk with the proposed alternative model and it is the second with the previous

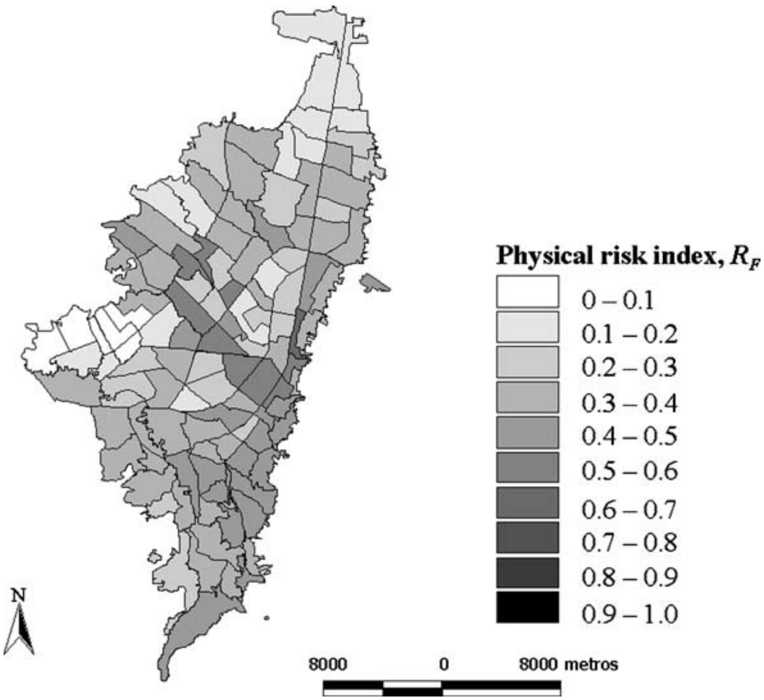

Figure 8. Physical risk index, R_F, for the UPZ of Bogota.

one. The other localities maintain a similar order of the Figures 12 and 13.

3.2. SEISMIC RISK OF BARCELONA

The city of Barcelona, Spain, is subdivided in ten districts (see Figure 14), 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). Figure 15 shows the physical risk scenario, calculated considering the 248 small ZRP zones. The impact factor was calculated by district, due to the availability of data at this level only.

Table XI shows examples of the physical risk descriptors for some of the 248 ZRP. Table XII presents examples of the physical risk factors.

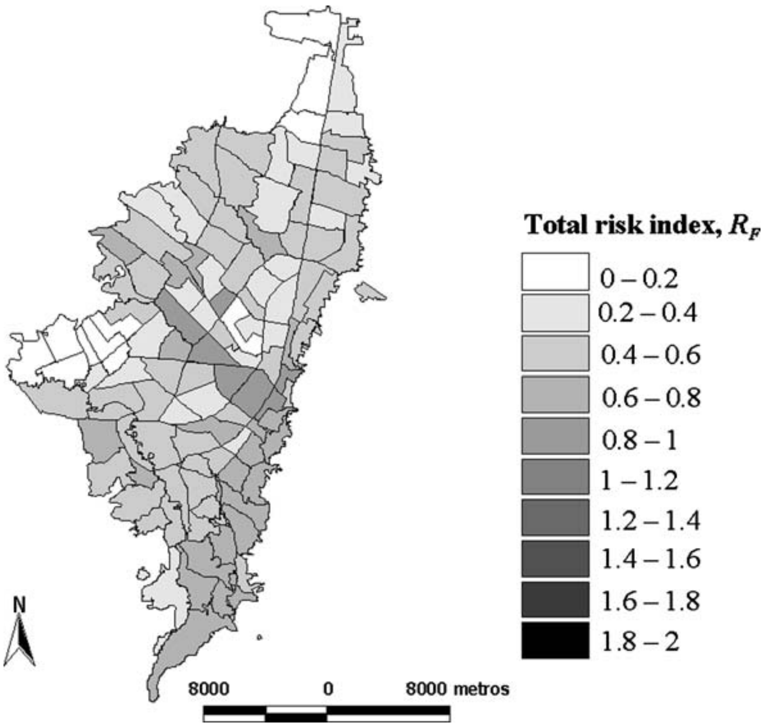

Figure 9. Total risk index, R_T, for the UPZ of Bogota.

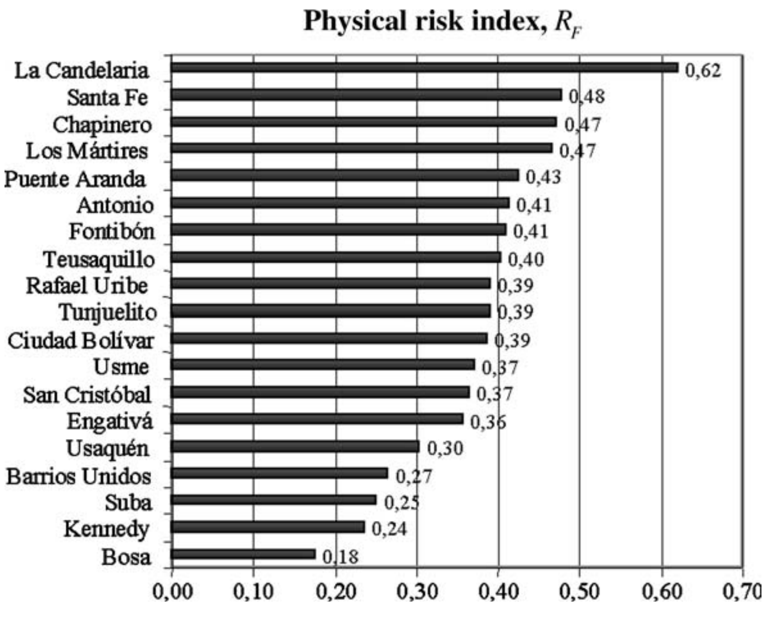

Figure 10. Physical risk index for the localities of Bogota, in descendent order.

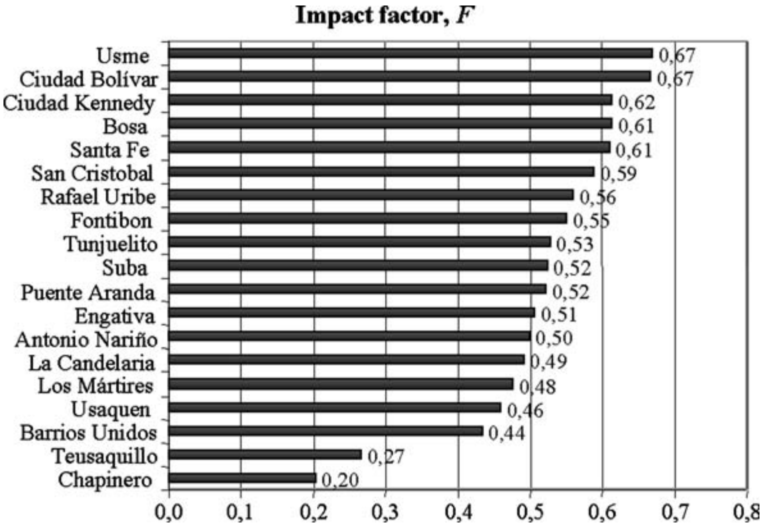

Figure 11. Impact factor for the localities of Bogota, in descendent order.

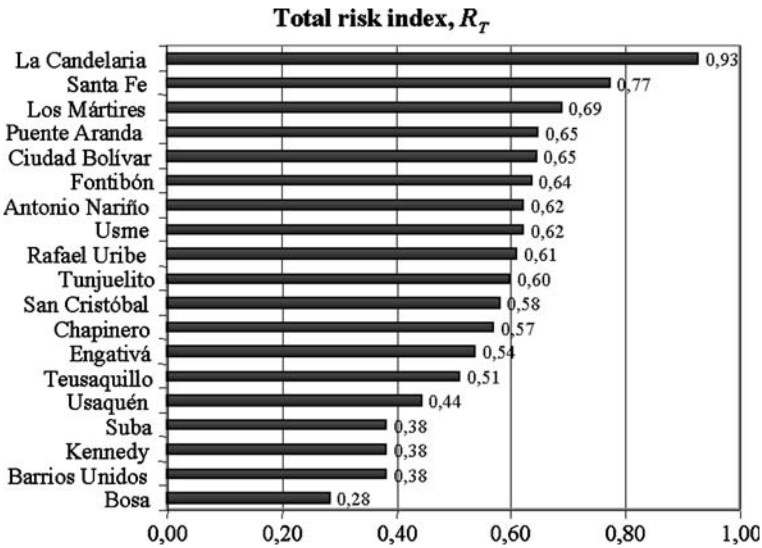

Figure 12. Total risk index for the localities of Bogota, in descendent order.

Table XIII shows the values for descriptors of social fragility and lack of resilience, and Table XIV displays the aggravating factors obtained by applying the transformation functions (Figures 2–4). In addition,

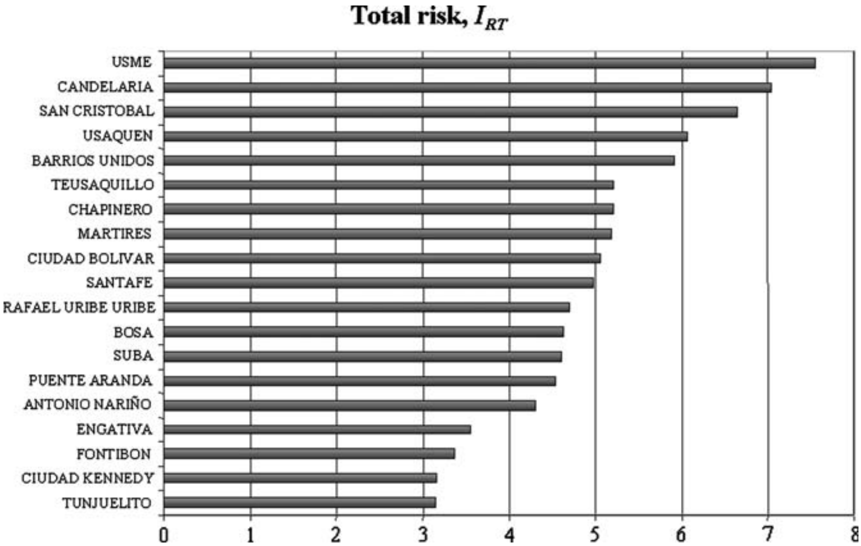

Figure 13. Total risk index for the localities of Bogota, obtained with the Cardona's model.

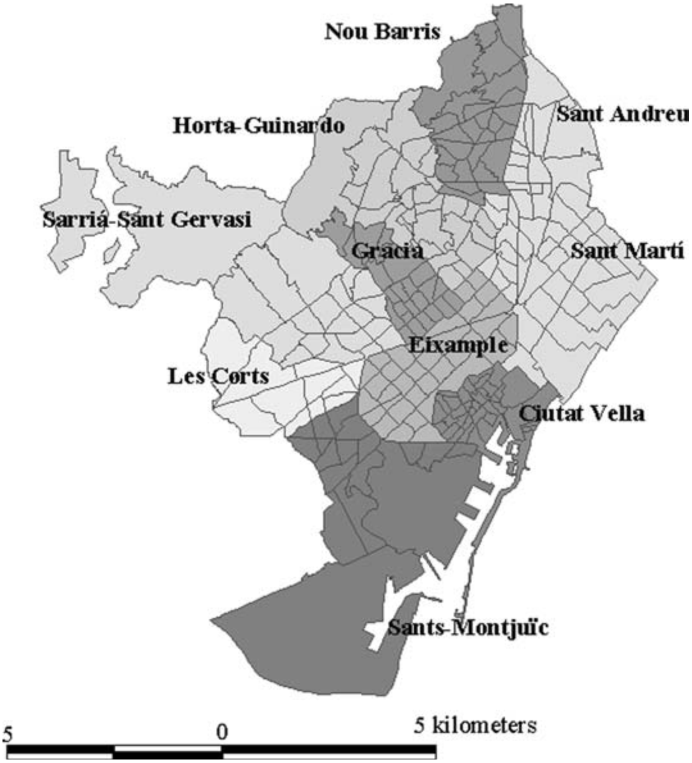

Figure 14. Territorial division of Barcelona.

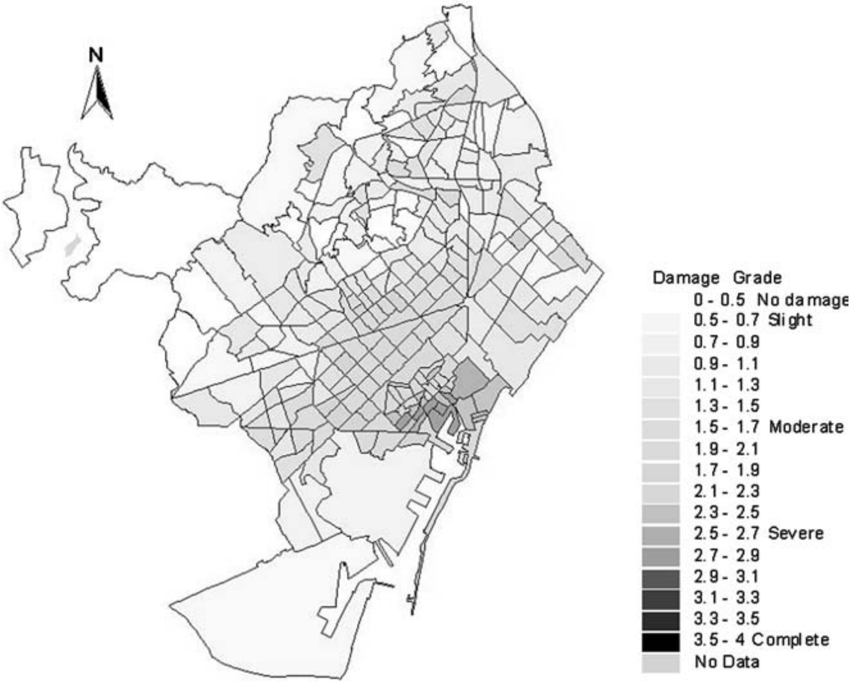

Figure 15. Physical risk scenario for Barcelona, using 248 small statistical zones (ZRP).

Table XIV, at the bottom, shows the average values of the factors for the city, normalised using the density of population. Table XV presents some examples of the final results of the physical risk index, the impact factor and total risk index for each ZRP zone. The weights are the same as those used in Bogota (Tables IV and V). Figures 16–18 show the results for the physical risk index, the impact factor and the total risk index for Barcelona using the model proposed above.

3.3. COMPARISON AND DISCUSSION OF THE RESULTS

The results obtained for Bogota have been compared with those obtained for Barcelona. Table XVI shows the average risk values for both cities. Bogota is located in a zone with intermediate seismic hazard, whereas Barcelona is located in a zone with low to moderate seismic hazard. The average values obtained for the physical risk index, R_F, clearly reflect this situation. It is interesting to remark that the results obtained for the impact factor, F, are not so different for both cities. The lowest values of this impact factor are similar (0.20 for the locality of Chapinero in Bogota and 0.18 for the district of Sarrià in Barcelona). The difference between the

Table XI. Examples of descriptor values of physical risk.

ZRP	X_{RF1}	X_{RF2}	X_{RF3}	X_{RF4}	X_{RF5}	X_{RF6}	X_{RF7}	X_{RF8}	X_{RF9}
001	16.9	6	12	0.02	0.02	0.02	0.17	0.32	0.025
002	19.5	10	21	0.02	0.02	0.02	0.17	0.32	0
003	19.7	9	19	0.02	0.02	0.02	0.17	0.32	0
004	20.5	6	12	0.02	0.02	0.02	0.17	0.32	0.2
005	20.7	7	15	0.02	0.02	0.02	0.17	0.32	0.2
006	22.2	5	11	0.02	0.02	0.02	0.17	0.32	0
007	24.2	7	14	0.02	0.02	0.02	0.17	0.32	0.2
008	10.1	3	6	0.02	0.02	0.02	0.17	0.32	0
009	8.9	2	5	0.02	0.02	0.02	0.17	0.32	0
010	8.3	4	8	0.02	0.02	0.02	0.17	0.32	0
...	...	...	...	...	...	...	...	...	...
240	3.9	3	6	0.02	0.02	0.02	0.17	0.32	0.05
241	1.6	4	8	0.02	0.02	0.02	0.17	0.32	0
242	2.4	5	10	0.02	0.02	0.02	0.17	0.32	0.025
243	11.1	19	40	0.02	0.02	0.02	0.17	0.32	0.025
244	2.9	7	15	0.02	0.02	0.02	0.17	0.32	0
245	8.4	16	34	0.02	0.02	0.02	0.17	0.32	0
246	3.3	7	15	0.02	0.02	0.02	0.17	0.32	0.025
247	3.3	8	18	0.02	0.02	0.02	0.17	0.32	0.025
248	4.9	9	20	0.02	0.02	0.02	0.17	0.32	0

highest values in the two cities is more noticeable (0.67 for the locality of Usme in Bogota and 0.71 for the district of Sant Marti in Barcelona). Although the highest value for Barcelona is larger than the highest value of Bogotá, the average value for Barcelona is smaller than the value for Bogotá. This is the aspect which shows the big difference between the cities regarding the holistic seismic risk. The proposed methodology, which permits a unified holistic evaluation of risk, allows performing in the future comparisons among other different cities worldwide.

4. 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 issues related to the development of communities that contribute to the creation of risk. At the urban level, for example, vulnerability

Table XII. Factors and physical risk index, R_F, for Barcelona.

ZRP	F_{RF1}	F_{RF2}	F_{RF3}	F_{RF4}	F_{RF5}	F_{RF6}	F_{RF7}	F_{RF8}	F_{RF9}	R_F
001	0.952	0.0288	0.0512	0.02	0.02	0.02	0.17	0.32	0.025	0.306
002	0.999	0.08	0.157	0.02	0.02	0.02	0.17	0.32	0	0.331
003	1	0.0648	0.128	0.02	0.02	0.02	0.17	0.32	0	0.328
004	1	0.0288	0.0512	0.02	0.02	0.02	0.17	0.32	0.2	0.336
005	1	0.0392	0.08	0.02	0.02	0.02	0.17	0.32	0.2	0.340
006	1	0.02	0.043	0.02	0.02	0.02	0.17	0.32	0	0.316
007	1	0.0392	0.0697	0.02	0.02	0.02	0.17	0.32	0.2	0.339
008	0.51	0.0072	0.0128	0.02	0.02	0.02	0.17	0.32	0	0.172
009	0.396	0.0032	0.00889	0.02	0.02	0.02	0.17	0.32	0	0.139
010	0.344	0.0128	0.0228	0.02	0.02	0.02	0.17	0.32	0	0.126
...	...	...	...	...	...	...	...	...	...	...
240	0.0761	0.0072	0.0128	0.02	0.02	0.02	0.17	0.32	0.05	0.053
241	0.0128	0.0128	0.0228	0.02	0.02	0.02	0.17	0.32	0	0.032
242	0.0288	0.02	0.0356	0.02	0.02	0.02	0.17	0.32	0.025	0.041
243	0.604	0.289	0.564	0.02	0.02	0.02	0.17	0.32	0.025	0.279
244	0.042	0.0392	0.08	0.02	0.02	0.02	0.17	0.32	0	0.048
245	0.353	0.205	0.411	0.02	0.02	0.02	0.17	0.32	0	0.183
246	0.0544	0.0392	0.08	0.02	0.02	0.02	0.17	0.32	0.025	0.054
247	0.0544	0.0512	0.115	0.02	0.02	0.02	0.17	0.32	0.025	0.058
248	0.12	0.0648	0.142	0.02	0.02	0.02	0.17	0.32	0	0.078
Barcelona	0.152	0.017	0.033	0.020	0.020	0.020	0.170	0.320	0.031	0.076

Table XIII. Values for the aggravating descriptors for social fragility and lack of resilience factors of Barcelona.

District	X_{FS1}	X_{FS2}	X_{FS3}	X_{FS4}	X_{FS5}	X_{FR1}	X_{FR2}	X_{FR3}	X_{FR4}	X_{FR5}	X_{FR6}
Ciutat Vella	0.2	119	252.87	0.8	12690	4.9650	11	0.0828	15	1	1
Eixample	0	119	60.04	0.3	14186	6.1475	14	0.0180	18	4	1
Sant-Montjuic	0	102	73.61	0.3	6834	0	0	0.1219	15	3	1
Les Corts	0	81	30.99	0.1	14080	10.6864	24	0.0424	18	4	1
Sarrià-Sant Gervasi	0	95	30.99	0	11647	10.8704	24	0.0194	8	4	1
Gràcia	0	115	42.66	0.2	16570	7.1269	16	0.0324	8	4	1
Horta-Guinardó	0.1	95	36.00	0.5	21573	16.1716	36	0.0369	8	2	1
Nou Barris	0.1	95	31.54	0.8	28256	0	0	0.0430	10	1	1
Sant Andreu	0.1	91	31.54	0.5	19890	1.1325	3	0.0198	10	2	1
Sant Martí	0.3	93	42.44	0.8	19069	0	0	0.0337	3	1	1

Table XIV. Impact factor, F, computed with aggravating factors of social fragility, F_{FS}, and lack of resilience, F_{FR} for Barcelona.

District	F_{FS1}	F_{FS2}	F_{FS3}	F_{FS4}	F_{FS5}	F_{FR1}	F_{FR2}	F_{FR3}	F_{FR4}	F_{FR5}	F
Ciutat Vella	0.0918	0.00061	0.0452	0.8	0.342	0.964	0.142	0.461	0	0.5	0.4437
Eixample	0	0.00061	0.000111	0.3	0.471	0.925	0.00889	0.993	0	0.5	0.2796
Sant-Montjuic	0	0.000347	0.000612	0.3	0.0364	1	1	0.0806	0	0.5	0.2558
Les Corts	0	0.000123	0	0.1	0.461	0.755	0	0.893	0	0.5	0.2270
Sarrià-Sant Gervasi	0	0.00026	0	0	0.265	0.769	0	0.991	0	0.5	0.1785
Gràcia	0	0.000542	0	0.2	0.678	0.894	0	0.949	0	0.5	0.2947
Horta-Guinardó	0.0102	0.00026	0	0.5	0.947	0.436	0	0	0	0.5	0.3875
Nou Barris	0.0102	0.00026	0	0.8	1	1	1	0.889	0	0.5	0.6164
Sant Andreu	0.0102	0.000215	0	0.5	0.882	0.997	0.92	0.99	0	0.5	0.5042
Sant Martí	0.255	0.000237	0	0.8	0.84	1	1	0.943	0.633	0.5	0.6591
Barcelona	0.04	0.00033	0.00352	0.48	0.69	0.87	0.45	0.75	0.54	0.5	0.42

Table XV. Seismic risk of Barcelona.

ZRP	R_F	F	R_T
001	0.306	0.444	0.442
002	0.331	0.444	0.479
003	0.328	0.444	0.473
004	0.336	0.444	0.485
005	0.340	0.444	0.491
006	0.316	0.444	0.456
007	0.339	0.444	0.489
008	0.172	0.444	0.248
009	0.139	0.444	0.200
010	0.126	0.444	0.182
...	...	...	...
240	0.053	0.659	0.088
241	0.032	0.659	0.053
242	0.041	0.659	0.068
243	0.279	0.659	0.462
244	0.048	0.659	0.080
245	0.183	0.659	0.303
246	0.054	0.659	0.089
247	0.058	0.659	0.097
248	0.078	0.659	0.130
Barcelona	0.0759	0.42	0.1102

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 risk increasing. Therefore, the potential negative consequences are not only related to the effects of the hazardous event as such, but also to the capacity to absorb the effects 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 of such risk. This parametric approach is not more than a model formulated in the most realistic possible manner, to which corrections or alternative figures may be continuously introduced. The consideration of physical aspects allowed the construc-

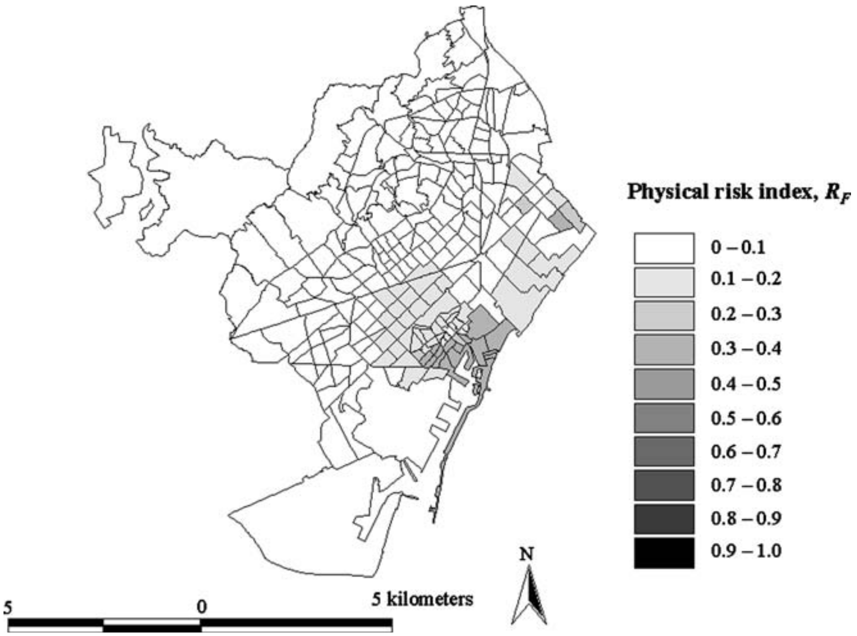

Figure 16. Physical risk index for Barcelona, using 248 small statistical zones (ZRP).

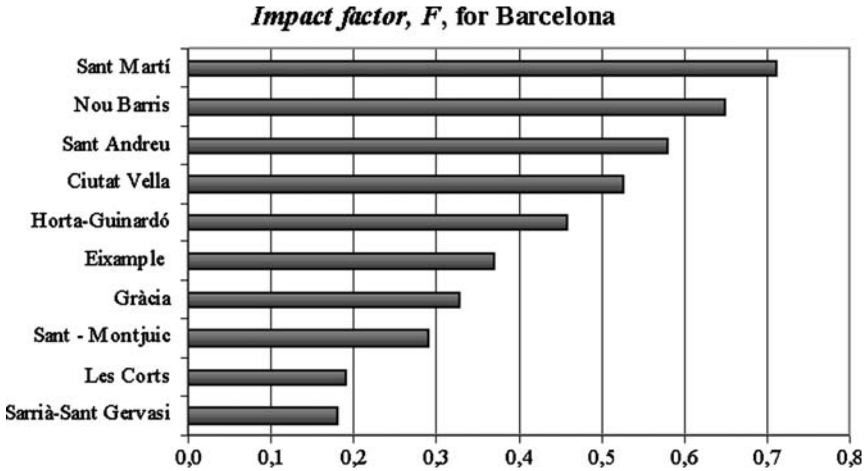

Figure 17. Impact factor for the districts of Barcelona.

tion 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 dam-

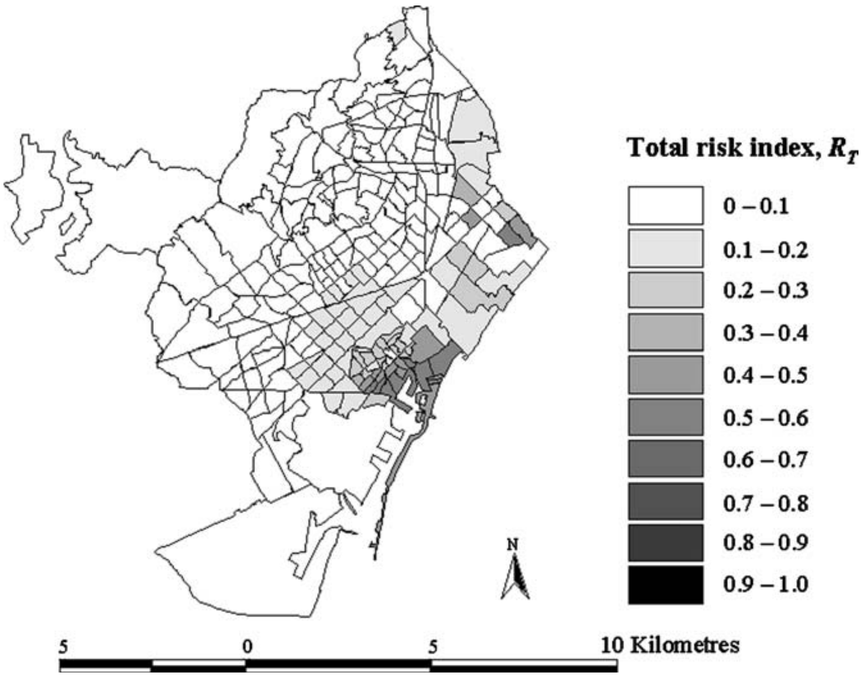

Figure 18. Total risk index for Barcelona, using the 248 small statistical zones (ZRP).

Table XVI. Comparison of the mean values between Bogota and Barcelona.

Index	Bogota	Barcelona
Physical risk, R_F	0.225	0.0759
Impact factor, F	0.663	0.42
Total risk, R_T	0.374	0.1102

age (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 in risk reduction decision-making. It permits the follow-up of the risk situation and the effectiveness 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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Appendix: Calculation of the Weighting Factors

The Hierarchic Analytical Process – AHP is a technique used for the decision making with multiple attributes (Saaty, 1987, 2001; Saaty and Vargas, 1991). It allows the decomposition of a problem into a hierarchy and this assures that the qualitative and quantitative aspects of the problem are incorporated in the evaluation process, during which the opinion is extracted systematically by means of pair-wise comparisons. AHP allows the application of data, experience, knowledge, and intuition of a logical and deep form.

AHP is a compensatory decision methodology because alternatives that are efficient with respect to one or more objectives can compensate by their performance with respect to other objectives. AHP allows for the application of data, experience, insights, and intuition in a logical and thorough way within a hierarchy as a whole. In particular, AHP as weighting method enables decision-maker to derive weights as opposed to arbitrarily assign them (JRC-EC, 2002, 2003).

The core of AHP is an ordinal pair-wise comparison of attributes, sub-indicators in this context, in which preference statements are addressed. The strength of preference is expressed on a semantic scale of 1–9, which keeps measurement within the same order of magnitude. A preference of 1 indicates equality between two sub-indicators while a preference of 9 indicates that one sub-indicator is 9 times larger or more important than the one to which it is being compared. These comparisons provide the matrix of Table A.1, in which, for example, the factor F_{RF7} is five times more important than the factor F_{RF1}.

The relative weights of the sub-indicators are calculated using an eigenvector technique. One of the advantages of this method is that it allows checking the consistency of the comparison matrix through the calculation of its eigenvalues and of a consistency index.

AHP tolerates inconsistency through the amount of redundancy. For a matrix of size $n \times n$, only $n-1$ comparisons are required to establish weights for n indicators. The actual number of comparisons performed in AHP is $n \times (n-1)/2$. This redundancy is a useful feature as it is analogous to estimating a number by calculating the average of repeated observations. This results in a set of weights that are less sensitive to errors of judgment. In addition, this redundancy allows for a measure of these judgment errors by providing a means of calculating a consistency ratio CR (Saaty, 1987; Karlsson, 1998)

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{CI}_{\mathrm{random}}} \tag{A.1}$$

obtained as a relation between a consistency index

$$\mathrm{CI} = \frac{\lambda_{\max} - n}{n - 1} \tag{A.2}$$

and the value of the same consistency index $\mathrm{CI}_{\mathrm{random}}$ obtained for a comparison matrix randomly generated, were $\lambda_{\max}$ is the principal eigenvalue of the pair wise comparison matrix. According to Saaty, a good precision is assured for small consistency ratios (CR less than 0.1 are suggested as a rule-of-thumb, although even 0.2 is often cited). If this condition is not

Table A.1. Matrix of comparisons for physical risk.

	F_{RF1}	F_{RF2}	F_{RF3}	F_{RF4}	F_{RF5}	F_{RF6}	F_{RF7}	F_{RF8}
F_{RF1}	1	4	4	2	3	3	5	5
F_{RF2}	0.25	1	1	0.5	1	1	3	3
F_{RF3}	0.25	1	1	0.5	1	1	3	3
F_{RF4}	0.50	2	2	1	2	2	4	4
F_{RF5}	0.33	1	1	0.5	1	1	3	3
F_{RF6}	0.33	1	1	0.5	1	1	3	3
F_{RF7}	0.20	0.33	0.33	0.25	0.33	0.33	1	1
F_{RF8}	0.20	0.33	0.33	0.25	0.33	0.33	1	1

Eigenvalue = 8.11.
CI = 0.0152.
CR = 0.0108.

achieved, the problem has to be studied again and the comparison matrix revised. Once achieved a good consistency, the principal eigenvector is calculated and normalized. This normalization is performed by dividing each element of the eigenvector by the sum of the values of its elements. The elements of this eigenvector are the values of the weighting factors. Table A.2 shows the weighting factors obtained starting from the pair wise comparison matrix of Table A.1. Table A.3 contains the pair wise comparison matrix for the aggravating factors obtained starting from the opinion of experts while the weights calculated by applying the AHP are given in Table A.4.

Table A.2. Importance for physical risk.

	Principal eigenvector	Priority vector
F_{RF1}	0.7410	0.31
F_{RF2}	0.2420	0.10
F_{RF3}	0.2420	0.10
F_{RF4}	0.4368	0.19
F_{RF5}	0.2496	0.11
F_{RF6}	0.2496	0.11
F_{RF7}	0.0958	0.04
F_{RF8}	0.0958	0.04

Table A.3. Matrix of comparisons for the impact factor.

	F_{FS1}	F_{FS2}	F_{FS3}	F_{FS4}	F_{FS5}	F_{FR1}	F_{FR2}	F_{FR3}	F_{FR4}	F_{FR5}	F_{FR6}
F_{FS1}	1	4	4	1	1	3	3	4	4	3	3
F_{FS2}	0.25	1	1	0.25	0.25	0.5	0.5	1	1	0.5	0.5
F_{FS3}	0.25	1	1	0.25	0.25	0.5	0.5	1	1	0.5	0.5
F_{FS4}	1	4	4	1	1	3	3	4	4	3	3
F_{FS5}	1	4	4	1	1	3	3	4	4	3	3
F_{FR1}	0.33	2	2	0.33	0.33	1	1	2	2	0.5	0.5
F_{FR2}	0.33	2	2	0.33	0.33	1	1	2	2	0.5	0.5
F_{FR3}	0.25	1	1	0.25	0.25	0.5	0.5	1	2	0.33	0.33
F_{FR4}	0.25	1	1	0.25	0.25	0.5	0.5	0.5	1	0.33	0.33
F_{FR5}	0.33	2	2	0.33	0.33	2	2	3	3	1	1
F_{FR6}	0.33	2	2	0.33	0.33	2	2	3	3	1	1

Eigenvalue = 11.24.
CI = 0.024.
CR = 0.016.

Table A.4. Importance for the impact factor.

	Principal eigenvector	Priority vector
F_{FS1}	1.0000	0.18
F_{FS2}	0.2136	0.04
F_{FS3}	0.2136	0.04
F_{FS4}	1	0.18
F_{FS5}	1	0.18
F_{FR1}	0.33928	0.06
F_{FR2}	0.33928	0.06
F_{FR3}	0.21601	0.04
F_{FR4}	0.1895	0.04
F_{FR5}	0.47833	0.09
F_{FR6}	0.47833	0.09

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