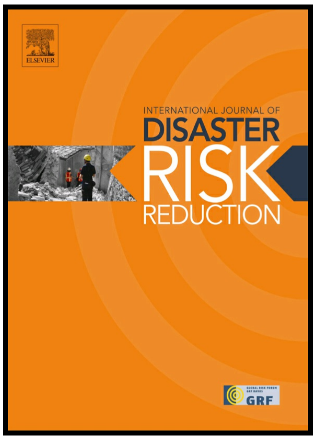

www.elsevier.com/locate/ijdr

Evaluation of social context integrated into the study of seismic risk for urban areas

N. Jaramillo, M.L. Carreño, N. Lantada

PII: S2212-4209(16)30021-8
DOI: http://dx.doi.org/10.1016/j.ijdrr.2016.05.002
Reference: IJDRR352

To appear in: *International Journal of Disaster Risk Reduction*

Received date: 14 January 2016
Revised date: 6 May 2016
Accepted date: 9 May 2016

Cite this article as: N. Jaramillo, M.L. Carreño and N. Lantada, Evaluation o social context integrated into the study of seismic risk for urban areas *International Journal of Disaster Risk Reductior* http://dx.doi.org/10.1016/j.ijdrr.2016.05.002

Evaluation of social context integrated into the study of seismic risk for urban areas

Jaramillo, N.; Carreño, M. L.; Lantada, N.

N. Jaramillo
Departamento de ciencias aplicadas y humanísticas, Escuela Básica de Ingeniería. Universidad de Los Andes.
Sector La Hechicera, Edificio B, 2º piso, Ala Norte, Merida, Estado Merida, Venezuela.
e-mail: nayive@ula.ve

M.L. Carreño
Centre Internacional de Metodes Numerics en Enginyeria (CIMNE). Division of Resistència de Materials i Estructures a l'Enginyeria (RMEE), Department of Civil and Environmental Engineering. Universitat Politècnica de Catalunya.
Jordi Girona 1-3, Building C1, Campus Nord UPC, 08034, Barcelona, Spain.
e-mail: liliana@cimne.upc.edu

N. Lantada
Division of Geotechnical Engineering and Geosciences. Department of Civil and Environmental Engineering
Universitat Politècnica de Catalunya.
Jordi Girona 1-3, Building D2, Campus Nord UPC, 08034, Barcelona, Spain.
e-mail: nieves.lantada@upc.edu

Abstract

Usually the seismic risk evaluation involves only the estimation of the expected physical damage, casualties or economic losses. This article corresponds to a holistic approach for seismic risk assessment which involves the evaluation of the social fragility and the lack of resilience. The complementary evaluation of social context aspects such as the distribution of the population, the absence of economic and social development, deficiencies in institutional management, and lack of capacity for response and recovery; is useful in order to have seismic risk evaluation suitable to support a decision making processes for risk reduction.

The proposed methodology allows a standardized assessment of the social fragility and lack of resilience, by means of an aggravating coefficient of which summarizes the characteristics of the social context using fuzzy sets and Analytic Hierarchy Process (AHP). The selection of 20 social indicators is based on the indicators used by urban observatories of United Nations and other social researchers. These indicators are classified according to social item they describe, in six categories. Applying the determination level analysis, thirteen prevailing social indicators are selected. The proposed methodology has been applied in the cities of Merida (Venezuela) and Barcelona (Spain).

Keywords: Urban seismic risk, social vulnerability, social fragility, lack of resilience, social indicators, holistic assessment of seismic risk.

1 Introduction

Several methodologies to evaluate risk due to natural hazards have been developed around the world. Usually, these methodologies provide an estimation of the potential physical damage in an urban area exposed to a specific natural hazard. In general, the physical damage is evaluated as damage both on buildings and lifelines, and different types of victims (people killed, injured, homeless and jobless).

Among the methodologies focused on seismic risk, some can be mentioned: the methodologies developed in EEUU, the ATC-13 [1], RADIUS [2] and HAZUS [3]; in Europe RISK-UE [4], LESSLOSS [5], SYNER-G [6], UPStrat-MAFA [7], the international initiative GEM [8] and the platform for probabilistic evaluation of risk CAPRA [9, 10].

The study of the seismic vulnerability of urban areas has been focused on the physical dimension without mention of the social dimension. However, this approach is changing; the relevant authorities are recognizing the importance of social aspects, such as, rapid population growth, access to good quality education and health, application and development of construction standards and level of governance, among others [11]. Globally there are different criteria and definitions to quantify the social context [12,13,14,15,16,17,18].

The seismic risk in urban areas is usually assessed in terms of physical losses that can occur. However, the risk can be evaluated from a comprehensive (or holistic) approach taking into account aspects of the social context like: economic and social development absence, deficiencies of institutional management, and lack of capacity for response and recover from a dangerous event.

The first international United Nations (UN) conference to fully recognize the challenge of urbanization was held in 1976 in Vancouver, Canada (Habitat I). This conference resulted in the creation of the precursors of UN-Habitat: the United Nations Commission on Human Settlements – an intergovernmental body – and the United Nations Centre for Human Settlements (commonly referred to as “Habitat”), which served as the executive secretariat of the Commission.

Twenty years later, 1996, the second United Nations Conference on Human Settlements (Habitat II) was held in Istanbul, Turkey. The aim was to address two main twin goals, namely 1) to ensure adequate shelter for all and 2) to guarantee sound development of human settlements in an urbanizing world. This conference was organized to assess two decades of progress since Habitat I and to set fresh goals for the new millennium. As result, the Habitat agenda was proclaimed containing over 100 commitments and 600 recommendations. Other global conferences were held between the conferences Habitat I and II, on which Habitat II reaffirmed its results.

The Millennium Declaration was adopted by the 189 members of the United Nations, on September 8th of 2000. It was based on global conferences held during the 1990s. The countries committed to the right to development, peace and security, gender equality, poverty eradication and sustainable human development. The Millennium Development Goals (MDGs) by 2015 consisting in 8 goals to be achieved, with 18 targets and a set of 48 technical indicators to measure their progress were established following the adoption of the Millennium Declaration. In 2007, the monitoring framework was updated to 21 targets and 60 indicators [19].

On the other hand, the Disaster Risk Management Index (DRMi or RMI) is widely used to evaluate the risk management performance of a country or a city. The DRMi brings together a group of indicators related to the risk management performance of the country. These reflect the organizational, development, capacity and institutional action taken to reduce vulnerability and losses, to prepare for crisis, and to efficiently recover [20, 21, 22]. This index is evaluated by using the qualitative measurement based on pre-established desirable referents (benchmarking) towards which risk management should be directed, according to its level of advance. For RMI formulation, four components or public policies are considered: Risk identification (RI), Risk reduction (RR), Disaster management (DM) and Governance and financial protection (FP). According to Carreño et al. [21, 22] the evaluation of each public policy takes into account 6 subindicators that characterize the performance of management in the country. Assessment of each subindicator is made using five performance levels: low, incipient, significant, outstanding and optimal, that corresponds to a range from 1 to 5, where 1 is the lowest level and 5 the highest.

As result of several World Conferences promoted by United Nations and others urban observatories, social indicators have been established to reflect different social aspects for any urban area around the world. These indicators are figures that allow describing complex and intangible aspects of the society.

Cardona [17] developed a conceptual framework and a model for risk analysis of a city from a holistic perspective, describing seismic risk by means of indices. He considered both “hard” and “soft” risk variables of the urban centre, taking into account exposure, socio-economic characteristics of the different areas or neighborhoods of the city and their disaster coping capacity or degree of resilience. One of the objectives of this model is to guide the decision-making in risk management, helping to identify the critical zones of the city and their vulnerability from the perspective of different professional disciplines. This method base the evaluation in a relative normalization of the involved indicators.

Carreño [23] developed an alternative method for Urban Risk Evaluation, starting from Cardona’s model [17], in which urban risk is evaluated using composite indicators or indices. Expected building damage and losses in the infrastructure, obtained from loss scenarios, are basic information for the evaluation of a physical risk index in each unit of analysis [24]. Often, when historical information is available, the seismic hazard can be identified and thus the most potential critical situation for the urban center. It conserves the approach based on indicators, but it improves the procedure of normalization and calculates the final risk indices in an absolute (non-relative) manner. This feature facilitates the comparison of risk among urban centers. The exposure and the seismic hazard were eliminated in the evaluation method because they are included into the calculation of the physical risk variables. The Carreño’s approach [24, 25] preserves the use of indicators and fuzzy sets or membership functions, proposed originally by Cardona [17], but in a different way. Afterwards, the robustness of the methodology was evaluated [26]. The methodology has been also applied to other cities as Metro-Manila, The Philippines, and Istanbul, Turkey [27, 28].

The holistic evaluation of risk using indices is achieved aggravating the physical risk by means of the contextual conditions, such as the socio-economic fragility and the lack of resilience. Input data about these conditions at urban level are necessary to apply the method. The socio-economic fragility and the lack of resilience are described by a set of indicators (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 is expressed as follows:

$$R_T = R_F\left(1 + F\right) \qquad (1)$$

where R_T is the total risk index, R_F is the physical risk index and F is the aggravating coefficient. 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}, respectively. The descriptors used in this evaluation have different nature and units, the transformation functions standardize the gross values of the descriptors, transforming them into commensurable factors with values between 0 and 1.

An alternative method base on the fuzzy sets theory was proposed to be used in cases where information on physical risk, social fragility or lack and resilience are not available, but local expert opinion can be obtained [29, 30].

This paper proposes a methodology to calculate the aggravating coefficient by using standard indicators, easy to collect, measuring social aspects which can make the situation worse in the case that a seismic event occurs. This paper defines a minimum and maximum number of indicators which can represent the social aspects that should be taken into account for a seismic risk evaluation.

2 Social context evaluation

This section proposes an indicator selection process in order to define the social indicators to be involved into the aggravating coefficient (F) for the holistic evaluation for the seismic risk. This selection is based on the indicators adopted and recognized at global level.

Based on several social indicators recognized at global level and the comprehensive or holistic approach for the seismic risk assessment, the following sub-sections show the selection process of social indicators that contribute to the aggravating coefficient, F, the determination of an optimum number of indicators (n), the calculation to establish the factors associated to each social indicator ($F_{\text{social indicator i}}$) and their participation weights (w_i) involved in equation 2.

$$F = \sum_{i}^{n} w_i * F_{\text{social indicator i}} \qquad (2)$$

2.1 Selection process for social indicators

The evaluation of the social context is a very complex task for almost all knowledge areas since the society is a very flexible system with a high degree of uncertainty. In order to evaluate de social vulnerability for urban areas several indicators have been proposed [14, 15, 23, 31 and 32].

The authors have selected twenty indicators among those used at global level to describe the social context for an urban area. These indicators correspond to indicators used by: Habitat Agenda [33], Istanbul+5 [34], the Millennium Gevelopment Goals [35] and the Carreño’s methodology [23, 24]. The selected indicators are classified into 6 categories: i) Dwelling (C1), ii) Social development and poverty eradication (C2), iii) Urban Planning (C3), iv) Governance (C4), v) Lack of resilience (C5) and vi) Demography (C6).

Two or more indicators describe each social aspect (see Table 1). Dwelling (C1) is composed by two indicators measuring social vulnerability related to the building in an urban area: Sufficient living area (Dw1) and dwelling condition (Dw2). Social development and poverty eradication (C2) consist of seven indicators measuring equality and integration in the development of urban settlements: Mortality rate (SD1), Infant mortality rate (SD2), Crime rate (SD3), Urban violence reduction policies (SD4), Poor households (SD5), Literacy rate (SD6) and Combined enrollment rate (SD7). Urban Planning (C3) consists of three indicators that measure the organization of the urban settlements: i) Growth of informal settlements (UP1), ii) Level of urban planning (UP2), and iii) Proportion of homes built in risk prone areas (UP3). Governance (C4) is composed of two indicators that measure the level of transparency, liability and efficiency in public policies for an urban area; this includes Disaster risk management index, DRMi (G1) [22], and Corruption perception index (G2). Lack of resilience (C5) consists of four indicators measuring the capacity response and recovery: i) Hospital beds (LR1), ii) Human resources in health (LR2), iii) Relief personnel (LR3), iv) Public space (LR4). Finally, the category Demography (C6) consists of two indicators that measure aspects of population distribution in urban settlements: i) Urban population density (D1), and ii) Urban population growth (D2).

Table 1 Categories and social indicators with their level of determination (D)

Category	Social indicator		Level determination (D)
	Code	Name	
C1: Dwelling	Dw1	Sufficient living area	+0.105
	Dw2	State of dwelling	+0.000
C2: Social development and poverty eradication	SD1	Mortality rate	-0.737
	SD2	Infant mortality rate	-0.526
	SD3	Crime rate	-0.105
	SD4	Urban violence reduction policies	-0.053
	SD5	Poor households	+0.158
	SD6	Literacy rate	+0.105
	SD7	Combined enrollment rate	-0.105
C3: Urban Planning	UP1	Growth of informal settlements	+0.684
	UP2	Level of urban planning	+0.316
	UP3	Homes built in risk prone areas	+0.105
C4: Governance	G1	Disaster risk management index, DRMi (Carreño et al., 2007b)	+0.105
	G2	Corruption perception index	-0.211
C5: Lack of resilience	LR1	Hospital beds	+0.053
	LR2	Human resources in health	+0.000
	LR3	Relief personnel	+0.000
	LR4	Public Space	-0.105
C6: Demography	D1	Population Density	+0.158
	D2	Urban population growth	+0.053

The number of indicators related to the social context is reduced from 20 to 13 by using a selection process based on the determination level for each indicator. This reduction avoids redundancy of the indicators and it allows weight or relative importance allocation.

The determination level or subordination of each indicator is obtained based on the dichotomous question "Does the indicator x affect the y indicator?". In order to process the answers, an nxn square matrix is ensemble, where n is the total number of variables. This matrix can be non-symmetric. The components of the matrix are 1 for affirmative responses and 0 for negative ones. By using this graph matrix, the influence rate (PI) and the dependency rate (PD) are evaluated. PI shows the number of variables that are influenced by the variable x; PD shows the number of variables that affect the variable x. In order to prioritize the variables, the level of dependence or independence is calculated by using Equation 3. It has a value between -1 (completely dependent) to +1 (fully independent).

$$\mathrm{D} = \frac{\mathrm{PI} - \mathrm{PD}}{\mathrm{n} - 1} \qquad (3)$$

The indicators are ranked by using the values for the determination level D. The indicators with a negative value for the determination level ($D < 0$) are discarded due to the dependency on the other indicators. Table 1 shows the 20 social indicators selected and their determination level. Based on these results 13 indicators are selected to be considered as the best indicators to describe the social context of an urban area. Two social indicators, Dw2 and UP2, are described below [11].

The State of dwelling (Dw2) describes the efficiency, effectiveness and accountability in their basic service delivery using two definitions according to the available information: 1) Lack of basic services, described by the number per thousand of households that are not connected (within their housing unit) to at least three of the following services: a) water transported in pipes, b) sewerage, c) electricity, and d) phone. 2) Dwellings without good condition represented by the number per thousand of dwellings in deficient, bad or ruins condition. This indicator provides useful information to define planning policies to achieve the objective of promoting access to basic services.

The indicator urban planning level (UP2) describes the level of urban land planning in order to meet the needs of the population. It corresponds to the category Urban planning (C3) and has the objective of promoting a geographically balanced structure of human settlements. It is based on qualitative information and is obtained from the response of six questions about the urban area:

1) Are there construction codes? (Yes/Not);

2) Are the construction codes used for the design and construction of the most of the new buildings? (Totally/ Partially/ Not or very little)

3) Are there risk maps for the area? (Yes/Not);

4) Has the premise of not build in risk areas been fulfilled? (Yes/Not);

5) Is disaster insurance of public and private buildings a common practice? (Yes/Not);

6) Is the disaster insurance mandatory for public buildings? (Yes/ Partially/ Not)

A numerical value is assigned to each response according to the following g criteria: 1 in the affirmative case (Yes or Totally); 2 in the negative case (Not or very little) and 1.5 in the case of the answer "partially". The sum of these values will be between 6 and 12, and it gives an idea about the urban planning level as follows: When the sum is very close to 6 indicates that the level of urban planning is high or has a good quality; if the sum value is close to 12, the level of urban planning is very low.

2.2 Transformation functions for the selected social indicators

The social indicators selected describe different aspects of the urban area, they have different nature and units, as it was already mentioned in section 1. Transformation functions were defined in order to standardize the gross values of the indicators into values between 0 and 1. Minimum and maximum values for each function were defined taking into account information about different urban centers around the world registered on international databases, urban observers and expert opinions.

Table 2 shows the minimum and maximum values adopted to define the transformation functions for the 13 social indicators as well as the rise trend for each case (see Figure 1).

Table 2 Lower and upper limits of the social indicators along with the trend of their transformation functions to contributing factor of aggravating coefficient

Social Indicator	Code	Limit min.-max.	Unit of measurement	Trend of the transformation function
Sufficient living area	Dw1	0-300‰	Overcrowded dwellings per thousand dwellings	Uptrend (Ut)
State of dwelling	Dw2	0-300 ‰	Dwellings with condition pi $^{(+)}$ per thousand dwellings	Uptrend (Ut)
Poor households	SD5	1-500‰	Poor dwellings per thousand dwellings	Uptrend (Ut)
Literacy rate	SD6	35-95%	Percentage (%)	Downtrend (Dt)
Growth of informal settlements	UP1	0-20	Ratio between self-construction dwellings without structural design and dwellings with structural design	Ut
Level of urban planning	UP2	6-12	Based on experts opinion (six Yes/No questions about urban planning)	Ut
Proportion dwelling built in location subject to risk	UP3	0-30‰	Dwellings located at risk per hundred thousand dwellings	Ut
Disaster risk management index (DRMi)	G1	10-80	Performance Level [22]	Dt
Hospital beds	LR1	2-12‰	Beds per thousand people	Dt
Human resources in health	LR2	1-6‰	Health professionals per thousand people	Dt
Relief personnel	LR3	0-7‰	Disaster relief workers per thousand people	Dt
Population Density	D1	4.000-25.000 Inhab/km^2	Inhabitants per square kilometers construction	Ut
Urban population growth	D2	0-10%	Annual Rate (%)	Ut

$^{(+)}$ condition p_1 = deficit in facilities (water, sewerage, electricity, and phone); condition p_2 = dwelling without good conditions

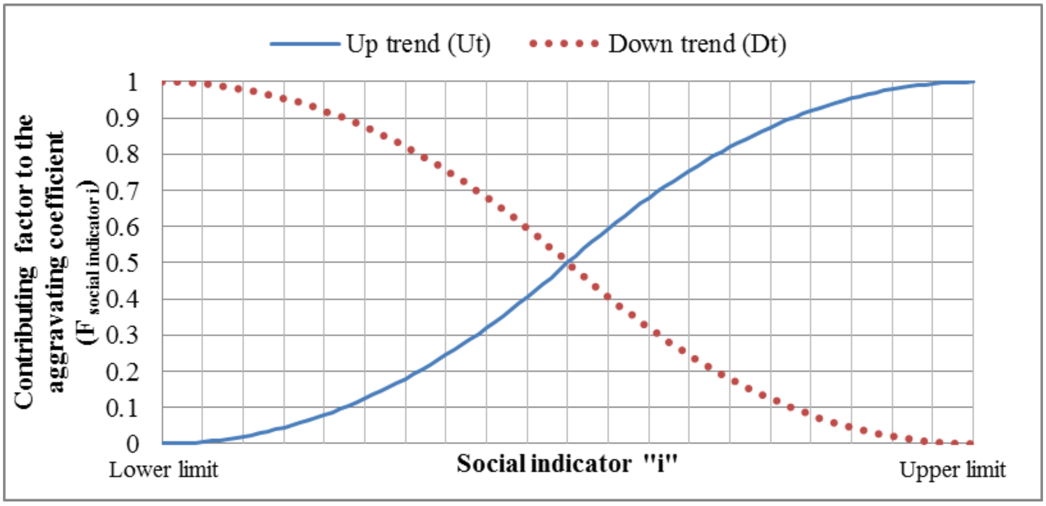


Figure 1. Transformation function for the value of the social indicator "i" to contributing factor to the aggravating coefficient

The transformation functions may have an up or down trend (see Figure 1). The functions with an uptrend have zero value for indicator values between 0 and the minimum value stablished; and they have a one value for indicator values greater than the maximum value. Functions with a down trend have the opposite behavior, they have value one for indicator values between 0 and the minimum value stablished, and they have a value zero for indicator values greater than the maximum value.

2.3 Evaluation of the aggravating coefficient

The aggravating coefficient is calculated as the weighted sum of the n contributing factors, this article deals with two cases: 13 selected indicators and 6 indicators (one for each category). The participation weights are defined by using the Analytical Hierarchical Process (AHP). AHP is a technique widely used for multi-attribute decision making. It allows the application of data, experience, knowledge, and intuition of a logical and deep form [22, 36]. The core of AHP is an ordinal pairwise comparison of attributes, indicators in this context, in which preference statements are addressed. For a given objective, the comparisons are made per pairs of indicators by first posing the question ‘‘Which of the two is the more important?’’ and second ‘‘By how much?’’ The strength of preference is expressed on a semantic scale of 1–9, where 1 indicates equality between two indicators while a preference of 9 indicates that one indicator is 9 times larger or more important than the one to which it is being compared.

The relative weights of the indicators are calculated using an eigenvector technique. One of the advantages of this method is that it is able to check the consistency of the comparison matrix through the calculation of the eigenvalues. This consistency is represented by the Consistency Rate (CR). If the CR is much in excess of 0.1 the judgements are untrustworthy [36].

2.3.1 General case

The aggravating coefficient (F) is calculated by using the 13 social indicators selected with the determination level. The contributing weights are defined applying the AHP with an acceptable Consistency Rate (CR=0.0987<0.10), (Table 3).

Table 3 Weights participation of the contributing factors to the aggravating coefficient for simplified case (n = 13) and case by category (n = 6)

Category	W_i (n=6)	Social indicator	W_i (n=13)
C1	0.168	Dw1	0.110
		Dw2	0.090
C2	0.123	SD5	0.051
		SD6	0.062
C3	0.224	UP1	0.054
		UP2	0.074
		UP3	0.067
C4	0.220	G1	0.092
C5	0.088	LR1	0.087
		LR2	0.115
		LR3	0.079
C6	0.177	D1	0.063
		D2	0.056

2.3.2 Simplified case: One indicator by category

In this case the aggravating coefficient is calculated based on 6 indicators, one for each proposed category (n=6). This simplification allows to facilitate the evaluation in two ways: i) by reducing the information search, the evaluation depends on the quality of the information, this selection focuses the research in the most relevant indicators. ii) The participation weights for each category are obtained by applying the AHP (see Table 3) with an acceptable Consistency Rate (CR=0.0866 < 0.1)

The proposed methodology allows adjusting the participation weights for the contributing factors to F when the number of available social indicators in the urban area is greater than 6 and fewer than 13.

The aggravating coefficient corresponds to a numerical value ranging between zero and one. However, with the objective to facilitate the analysis and comparison of different cases, it is convenient to express the aggravating coefficient in linguistic terms. Thus, in this study the aggravating coefficient is represented by using five levels: very low, low, medium, high and very high. The F numerical ranges associated with their equivalent language levels are shown in Table 4.

Table 4 Ranges for each level of seismic physical risk, R_{Fi}, Total seismic risk, R_T, and the aggravating coefficient, F

Level	Range for R_{Fi} and R_T	Range for F
Very low	(0.00 a 0.02]	[0.00 a 0.10]
Low	(0.02 a 0.18]	(0.10 a 0.30]
Moderate	(0.18 a 0.50]	(0.30 a 0.60]
High	(0.50 a 0.82]	(0.60 a 0.80]
Very High	(0.82 a 1.00]	(0.80 a 1.00]

3 Holistic evaluation of the seismic risk

As it was mentioned in section 1, from a holistic approach, the total risk depends on the direct effect, or physical risk (R_F), and the social context conditions (F), such as the socio-economic fragility and the lack of resilience indirect effects, which can to worsen the situation when a hazard event strikes an urban centre [20, 29]. This article standardizes the values of the Total risk index (R_T) of Equation 4 into a range between zero and one.

$$R_{Ti} = R_{Fi} \cdot (1 + F_i) \leq 1.0 \quad (4)$$

Where R_{Fi} corresponds to weighted sum:

$$R_{Fi} = \sum_{j}^{m} W_{RFi} * F_{RFi} \quad (5)$$

Where W_{RFi} are weights for each risk factor F_{RFi}

In order to make the analysis of the obtained results easier, this paper proposes to have pre-established levels and range of values for each component in the evaluation, these levels are defined in Table 4.

In summary, the process to perform the holistic seismic risk assessment proposed in this paper includes the following steps: a) to find and process information that represents, on the one hand , the physical damage that can occur due to a seismic event, and on the other hand, the social aspects that characterize the urban area; b) to evaluate the seismic physical risk index based on the potential physical damages; c) to calculate the aggravating coefficient based on the social aspects of the urban area, and finally; d) evaluate the total seismic risk index, based on physical seismic risk index and the aggravating coefficient.

4 Examples of application

The proposed holistic methodology for seismic risk evaluation was applied to two cities; both differ in their seismic hazard and location: Merida (Venezuela) and Barcelona (Spain).

4.1 Holistic seismic risk evaluation in Merida, Venezuela

The city of Merida, Venezuela, is located in the Nord-Est Venezuela, in the central part of Venezuela Andes. It is on a plateau or long terrace within a floodplain (Quaternary sediments), bounded by two mountain ranges: the Sierra Nevada in South-East and the Sierra de la Culata in North-West [37, 38].

Merida, with a total population of less than 250 thousand inhabitants is the capital of both the Estate of Merida, and the Libertador municipality. It is made up of 12 of the 15 parishes (in Spanish “Parroquias”) of Libertador municipality (Figure 2). The northern part of the city contains the parishes Arias and Milla partially, while the southern part contains the parishes: Osuna Rodríguez and Juan Rodríguez Suárez; the Eastern: Jacinto Plaza; the Western: Lasso de Vega, Caracciolo Parra Pérez, Mariano Picón Salas and Antonio Spinetti Dini; and the inner part of the city contains the parishes: El Llano, Sagrario and Domingo Peña. [39, 40, 41].

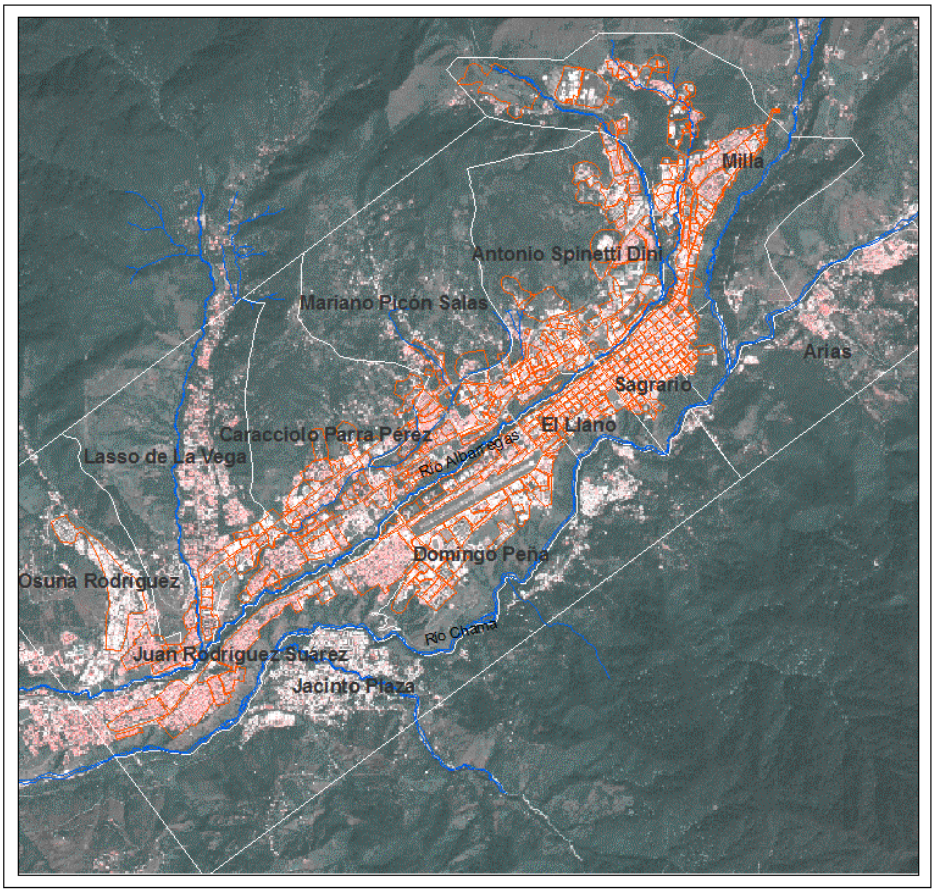


Figure 2. Location map of Merida, Venezuela, with parishes

In terms of seismicity, Merida is located within an area of high seismic activity (zone 4 and 5) according to the seismic classification of structural normative in Venezuela, which divides the country into seven zones with different seismic hazard [42]. Below the city runs the major tectonic fault in the western Venezuela, the Boconó fault, which forms part of the South American Plate [43].

The events that have shaken violently several populations of Merida state and specifically the city of Merida, are the earthquake of 1610, with an estimated Ms = 7.3 magnitude; the earthquake of 1812 with an estimated Ms = 7.0 magnitude, and the great earthquake of the Venezuelan Andes, the day 04/28/1894 at 10:00 pm, with an estimated magnitude Ms = 7.0 [44].

This research considers the seismic hazard in terms of macroseismic intensity, according to the European Scale EMS-98 [45], considering two scenarios defined by seismic intensities VIII and IX. In addition, the possible effects induced by liquefaction and landslides were evaluated through HAZUS-99 methodology by Castillo [40]. These local effects are indicated with an increment in intensity of 0.5 degrees in some areas of the city of Merida.

To present the numerical and cartographic results of seismic risk assessment in Merida the political-territorial division of parishes is used, because it helps to determine the effect of social context. Parishes are demarcations of local character within the territory of a municipality, created in order to decentralize local government, promote citizen participation and enhance of local public services.

4.1.1 Physical risk

To evaluate the physical risk index of each of the parishes of the city of Merida, damage of elements exposed to seismic hazard are estimated, such as: collapsed buildings area, damage to lifelines and human victims (dead, injured and people who become homeless).

Building damages

Based on the classification of buildings (BTM, Building Typology Matrix) of Risk-UE Project [46], Castillo [40] identifies the following seven predominant building typologies in the city of Merida, and their respective more plausible vulnerability indexes (between zero and one), indicated between brackets:

- Reinforced concrete frame buildings, with or without seismic design: RC3.1 (0.402), RC3.2 (0.522), RC5 (0.384), NENG_RC (0.685).
- Adobe or earth houses, with timber or similar roofs and slabs, M2 (0.840).
- Classic steel structures, with horizontal and vertical elements, S1 (0.363).
- Type of buildings called “Rancho”, extremely precarious houses built by their habitants with very low quality materials and without any design code, R (0.900).

As in previous studies [40, 47, 48], the metropolitan area of Merida is divided into sectors, considering the homogeneity (similarity among buildings), physical barriers (especially the two rivers close to the city) and accessibility (bridges and roads). Each sector is divided into several subsectors, such that most of the buildings in each subsector belong to the same class of physical vulnerability. This implies that there is no information about the specific location of each type of buildings. However, sectors and subsectors provide useful information on the distribution of the different structural typologies within them.

In this research, the database of buildings used by Castillo [40] (16,147 buildings) was completed, incorporating all existing buildings in a sector (Los Curos) of the parish Osuna Rodriguez, which had not been considered in the previous studies [40, 47]. These new buildings were characterized with the classification matrix of buildings of the Risk-UE Project, adopted for the city of Merida in Castillo [36]. Therefore, the total number of buildings considered in Merida is 17,664 and the percentage distribution of typologies in the city is: 40.27% for NENG-RC, 33.03% for RC3.1, 15.20% for M2 and 9.86%, for RC3.2, while each of the R, S1 and RC5 typologies exhibit a percentage less than 1%. Table 5 shows the distribution of typologies by Parish.

Table 5. Percentage of building typologies for each Parish (based on [40]).

Parish	% Ranchos (R)	% Adobe (M2)	% NENG-RC	% RC3.2	% RC3.1	% RC5	% S1	Total
Antonio Spinetti Dini	0.8	11.5	58.0	0.6	26.7	1.6	0.8	100
Arias	0.2	24.7	21.3	7.9	8.0	0.0	0.5	63
Caracciolo Parra Pérez	0.3	11.4	29.4	3.6	54.6	0.1	0.7	100
Domingo Peña	0.0	9.8	47.0	12.5	6.5	0.0	0.0	76
El Llano	0.0	7.0	9.8	8.8	5.2	0.0	0.1	31
Juan Rodríguez Suárez	0.0	0.0	0.1	0.8	53.3	0.0	0.0	54
Lasso de la Vega	0.0	0.7	14.6	8.5	74.2	2.0	0.0	100
Mariano Picón Salas	0.1	2.0	6.1	0.3	84.0	7.5	0.0	100
Milla	1.5	17.3	46.5	4.0	26.3	0.1	1.1	97
Osuna Rodríguez	0.0	0.0	84.0	4.2	11.6	0.0	0.1	100
Sagrario	0.0	4.8	1.6	1.6	0.7	0.0	0.4	9

Using the Vulnerability Index Method of the Risk-UE Project [46, 49] the damage probability matrices were established for each representative typology of the city for macroseismic intensities VIII and IX-X, and considering five damage states plus a no-damage state according to the macroseismic scale ESM-98. Then, using the damage probability matrices, the potential destroyed area for each parish to seismic intensities VIII and IX was estimated [11].

Lifelines

For the city of Merida-Venezuela potential damage in the system of potable water and the damage to the road system was evaluated. Based on the study of Astorga [50] about seismic damage of water pipelines network in Merida, a correspondence between the ten pressure zones and parishes of the city of Merida was performed. The descriptor of physical risk was estimated for the drinking water system, in terms of tears per kilometer in the different parishes for two seismic intensities VIII and IX [11]. The average damage in the transportation system was established as a weighted average of damage, depending on the length road affected by each of the levels of ground motion (peak ground displacement, PGD) for a given seismic intensity. For this purpose, different systems of urban roads were categorized, based on HAZUS-99 [3, 11].

Human casualties

It was considered appropriate to use the model of Risk-UE Project [51, 52, 53] to determine the number of victims given that, the area under study has a moderate seismic hazard [42] and the basic data that this model requires was available.

Index of physic risk

Once the physical risk of exposed elements in the parishes of Merida are estimated, they become contributing factors to physical seismic risk, applying the corresponding transformation functions. Subsequently, according to equation 5, for m= 6 categories and their respective weights w_{RFi}, values of seismic physical risk index are obtained for each of the parishes of the city in two seismic scenarios (intensity VIII and IX) (Figure 3).

Table 6 shows the values estimated for the physical damage (intensity IX) by parish for Merida: percentage of destroyed area (X_{RF1}), dead people per thousand inhabitants (‰) (X_{RF2}), injured people (‰) (X_{RF3}), homeless (‰) (X_{RF4}), potential damage in the system of potable water (tears per kilometer) (X_{RF5}), and damage for the road system (percentage affected of the road system) (X_{RF6}). Table 7 shows the obtained values for the physical risk factors based on the damage estimations of Table 6 and the Physical risk index, R_F.

Table 6. Indicators of seismic physical risk for the Merida’s parishes (intensity IX)

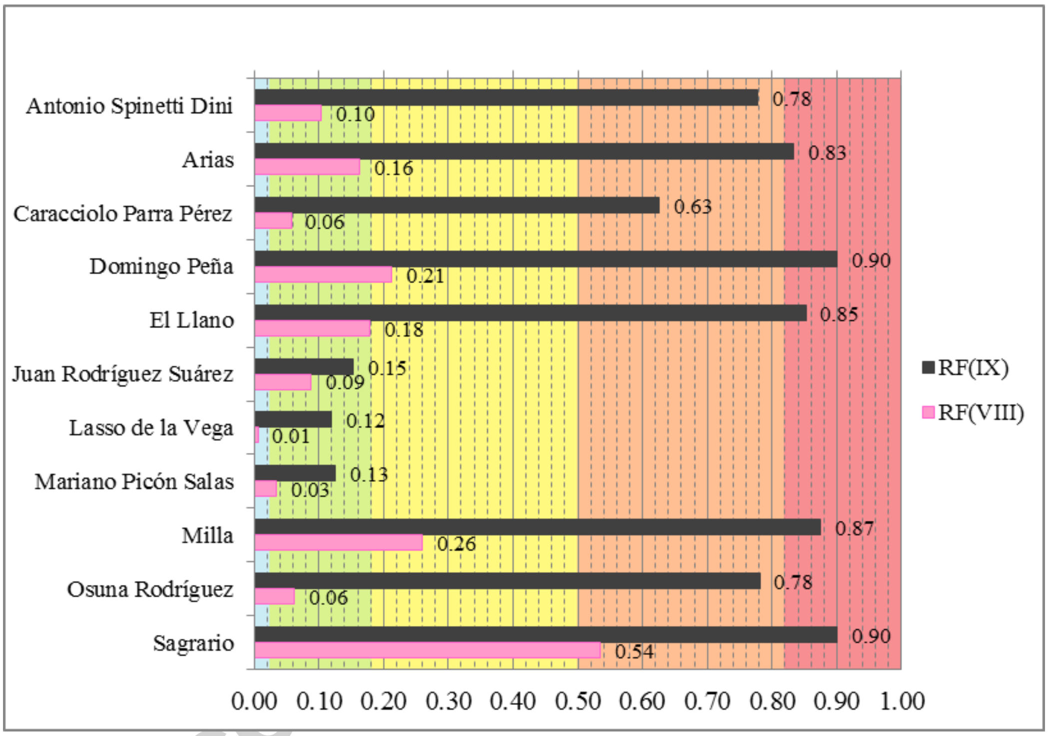
Parish	X_{RF1}	X_{RF2}	X_{RF3}	X_{RF4}	X_{RF5}	X_{RF6}
Antonio Spinetti Dini	21%	54.0	41.1	288.67	26.5	0%
Arias	32%	48.3	48.8	229.72	13.6	0%
Caracciolo Parra Pérez	14%	52.0	43.1	310.90	25.5	0%
Domingo Peña	23%	101.3	74.9	498.89	20.9	1%
El Llano	22%	77.6	70.5	387.07	33.7	0%
Juan Rodríguez Suárez	1%	9.1	6.0	108.81	82.8	1%
Lasso de la Vega	4%	4.1	2.9	34.42	17.2	0%
Mariano Picón Salas	3%	6.5	5.0	65.74	17.7	0%
Milla	23%	97.4	82.8	518.26	13.8	1%
Osuna Rodríguez	20%	57.0	36.4	307.10	15.1	1%
Sagrario	36%	164.1	169.0	700.77	27.2	0%

Table 7. Calculated factors of physical risk and Physiscal risk index (intensity IX)

Parish	F_{RF1}	F_{RF2}	F_{RF3}	F_{RF4}	F_{RF5}	F_{RF6}	R_F
Antonio Spinetti Dini	0.88	1.00	0.59	0.99	1.00	0.00	0.78
Arias	1.00	0.99	0.76	0.89	1.00	0.00	0.83
Caracciolo Parra Pérez	0.32	1.00	0.64	1.00	1.00	0.00	0.63

Domingo Peña	1.00	1.00	1.00	1.00	1.00	0.00	0.90
El Llano	0.84	1.00	0.99	1.00	1.00	0.00	0.85
Juan Rodríguez Suárez	0.01	0.07	0.01	0.26	1.00	0.00	0.15
Lasso de la Vega	0.04	0.01	0.003	0.03	1.00	0.00	0.12
Mariano Picón Salas	0.02	0.03	0.01	0.10	1.00	0.00	0.12
Milla	0.91	1.00	1.00	1.00	1.00	0.00	0.87
Osuna Rodríguez	0.97	1.00	0.47	1.00	1.00	0.00	0.78
Sagrario	1.00	1.00	1.00	1.00	1.00	0.00	0.90

Additionally, physical risk levels can be described by linguistic or numerical limits, which are delimited by vertical color stripes (both are described in table located at bottom of Figure 3).



Physical risk level	Very low	Low	Moderate	High	Very high
Range	$R_{Fi} \leq 0.02$	$0.02 < R_{Fi} \leq 0.18$	$0.18 < R_{Fi} \leq 0.50$	$0.50 < R_{Fi} \leq 0.82$	$0.82 < R_{Fi} \leq 1.00$

Figure 3 Seismic physical risk for intensities VIII, R_F(VIII), and IX, R_F(IX), in the parishes of the city of Merida, Venezuela. Bars in pink and grey color represent the physical seismic risk values for intensity VIII, R_F(VIII), and IX, R_F(IX) respectively.

4.1.2 Social Context

In order to calculate 11 of the 13 prevailing social indicators proposed in the methodology described in this article, for the city of Merida, information from different urban observers was used. Such urban observers were: Statistics Institute of Venezuela [54]; interviews with local experts in risk management (to establish the risk management index for 2010) and information from various local researchers

[39, 55, 56]. Information from Firefighters Group of Merida (internal census), and Andean Corporation (CORPOANDES) was also used. CORPOANDES, in the frame of the Simon Bolivar national project called Geographic Information System of the Region of the Andes (SIGRA), collected, organized, updated and generated statistical and cartographical information of different socio-economic aspects of Tachira, Merida and Trujillo [57].

The methodology was adapted to the city of Merida establishing 11 (n = 11) contributors to aggravation.Share weights are set using the AHP. Once the different prevailing social indicators of Merida are established, they become contributor factors of the aggravation generated by the social context, applying the corresponding transformation functions (section 2.2). Then, the numerical value of the aggravating coefficient (F) for is parish is obtained for the following two cases:

Case 1: adaptation of the general case of the proposed methodology, considering eleven factors contributing to the aggravation (n = 11) with their weights of participation (Table 8). Table 9 shows the values of the prevailing social indicators and Table 10 the calculated contributing factors, for the parishes.

Case 2: considering a factor for each of the six categories proposed (n = 6), with the weights given in the proposed methodology (Table 3). In this case, the aggravating coefficient corresponds to the combination of the six factors F(Dw1), F(SD5), F(UP2), F(G1), F(LR1) and F(D1) (Table 2). In both cases, the numerical values of the aggravating coefficient for each of the parishes studied in the city of Merida, correspond to the average level of aggravation (range from 0.30 to 0.60) (Figure 4).

Table 8. Weights participation (W_i) of the contributing factors to the aggravating coefficient by n =11

	Factor associated with social indicator i, F(social indicator i) i= 1, …, n												
	F(Dw1)	F(Dw2)	F(SD5)	F(SD6)	F(UP1)	F(UP2)	F(UP3)	F(G1)	F(LR1)	F(LR2)	F(LR3)	F(D1)	F(D2)
W_i	0.122	0.106	0.054	0.065	n/a	0.110	0.109	0.135	0.084	n/a	0.074	0.093	0.048

In Case 1 (n = 11), the parish of Sagrario has the highest aggravating coefficient and Domingo Peña parish has the lowest. In Case 2 (n = 6) the highest and lowest aggravating coefficient correspond to Antonio Spinetti Dini and Juan Rodriguez Suarez parishes, respectively.

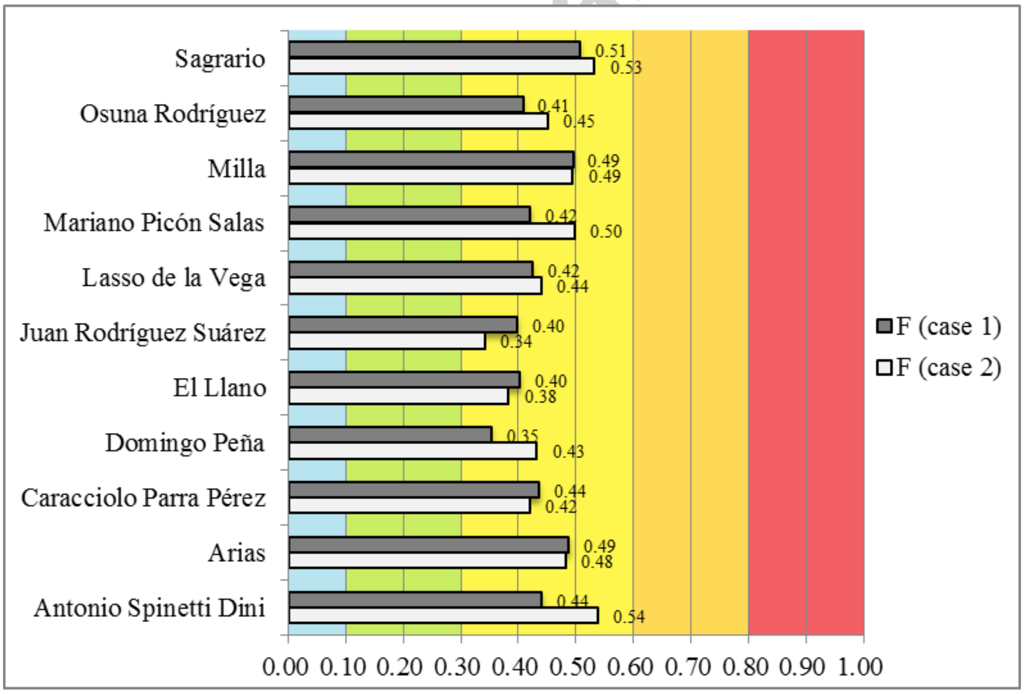
Table 9. Values of the prevailing social indicators for the parishes of Merida (Case 1)

	C1		C2		C3		C4	C5		C6	
Parish	Dw1	Dw2	SD5	SD6	UP2	UP3	G1	LR1	LR3	D1	D1
Antonio Spinetti Dini	69	67	154.06	0.97	9.5	974	34.55	2.21	0.74	1.50	0.89

Arias	94	81	193.27	0.95	9.5	2150	34.55	0.00	0.74	0.80	1.33
Caracciolo Parra Pérez	39	33	86.88	0.97	9.5	3524	34.55	0.24	4.62	0.70	5.82
Domingo Peña	57	2	105.71	0.96	9.5	1333	34.55	22.45	1.91	1.50	-1.01
El Llano	25	1	48.82	0.98	9.5	3703	34.55	8.11	1.91	1.10	-1.8
Juan Rodríguez Suárez	31	9	53.97	0.98	8.5	2292	34.55	1.51	1.86	0.60	-0.05
Lasso de la Vega	72	40	132.59	0.96	9.5	4963	34.55	0.00	4.62	0.60	2.57
Mariano Picón Salas	26	49	82.33	0.97	9	1951	34.55	3.37	4.62	1.70	-0.95
Milla	69	65	161.38	0.96	9.5	2426	34.55	1.06	0.74	1.20	-0.15
Osuna Rodríguez	84	12	130.52	0.96	10	5000	34.55	6.35	4.62	0.80	1.29
Sagrario	35	1	52.91	0.98	10	4718	34.55	0.00	1.91	1.50	-2.22

Table 10. Contributing factors calculated for the parishes of Merida

Parish	F(V1)	F(V2)	F(DS5)	F(DS6)	F(O2)	F(O3)	F(G1)	F(F1)	F(F3)	F(D1)	F(D2)
Antonio Spinetti Dini	0.10	0.10	0.19	0.00	0.65	0.21	0.75	0.99	1.00	0.55	0.02
Arias	0.20	0.15	0.30	0.00	0.65	0.84	0.75	1.00	1.00	0.07	0.03
Caracciolo Parra Pérez	0.03	0.02	0.06	0.00	0.65	1.00	0.75	1.00	0.31	0.04	0.65
Domingo Peña	0.07	0.00	0.09	0.00	0.65	0.39	0.75	0.00	0.95	0.55	0.00
El Llano	0.01	0.00	0.02	0.00	0.65	1.00	0.75	0.30	0.95	0.22	0.00
Juan Rodríguez Suárez	0.02	0.002	0.02	0.00	0.35	0.89	0.75	1.00	0.96	0.02	0.00
Lasso de la Vega	0.12	0.03	0.14	0.00	0.65	1.00	0.75	1.00	0.31	0.02	0.13
Mariano Picón Salas	0.01	0.05	0.05	0.00	0.50	0.76	0.75	0.96	0.31	0.71	0.00
Milla	0.10	0.09	0.21	0.00	0.65	0.93	0.75	1.00	1.00	0.29	0.00
Osuna Rodríguez	0.16	0.003	0.13	0.00	0.78	1.00	0.75	0.62	0.31	0.07	0.03
Sagrario	0.03	0.00	0.02	0.00	0.78	1.00	0.75	1.00	0.95	0.55	0.00



Aggravation level	Very low	Low	Medium	High	Very high
Range	F ≤ 0.10	0.10 < F ≤ 0.30	0.30 < F ≤ 0.60	0.60 < F ≤ 0.80	0.80 < F ≤ 1.00

Figure 4 Aggravating coefficient (F) by parish of the city of Merida, Venezuela: for the adaptation of the general case (case 1) for proposed methodology with 11 indicators, and for the simplified case (case 2)

4.1.3 Total seimic risk

The total seismic risk obtained with Equation 4, in each of the parishes of the city, for VIII and IX seismic intensity scenarios is shown in Figures 5 and 6 respectively. The values of total seismic risk are greater than physical seismic risk values, due to the average level of aggravation, which is generated by the social context of each of the parishes of the city.

The total seismic risk level is a level greater than the physical seismic risk level for the scenario of intensity VIII (Moderate level regarding to Low level.) in El Llano and Arias parishes (see arrows in Figure 5). Other parishes have a total seismic risk level similar to the level of physical seismic risk. For intensity IX parishes which increase one risk level relative to seismic physical seismic risk, from Moderate to High level, are: Antonio Spinetti Dini, Caracciolo Parra Perez, Osuna Rodríguez, and from Low to Moderate level: Juan Rodriguez Suarez and Mariano Picon Salas parishes; while the Very High level of risk remains unaltered in the parish Sagrario (see arrows in Figure 6).

The level of total seismic risk for the scenario of intensity IX is much greater than for the scenario of intensity VIII. The total seismic risk increases at least two levels in almost all parishes except Mariano Picon, Lasso de la Vega and Juan Rodriguez Suárez, because the predominant building types in these parishes are less vulnerable to seismic hazard. It should be noted that parishes Antonio Spinetti Dini, Caracciolo Parra and Rodriguez Osuna increase their level of total seismic risk from Low to Very High. The parishes of Arias, Domingo Peña, El Llano and Milla move from Moderate to Very High level. Parishes less affected by the aggravation coefficient (up only one level) are: Juan Rodriguez Suarez and Mariano Picon Salas.

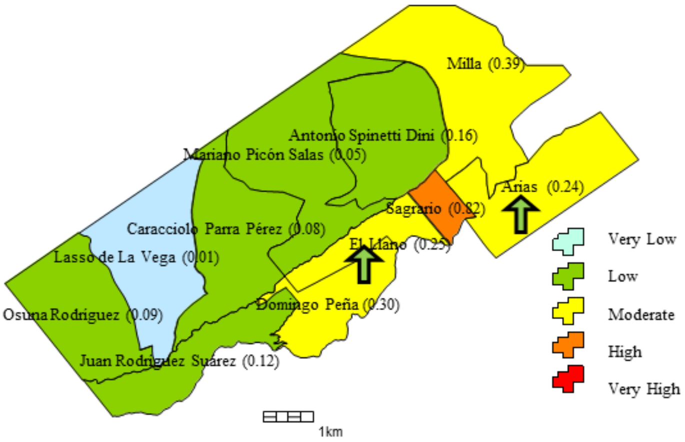


Figure 5. Total seismic risk to intensity VIII by parish of the city of Merida, Venezuela (R_T)

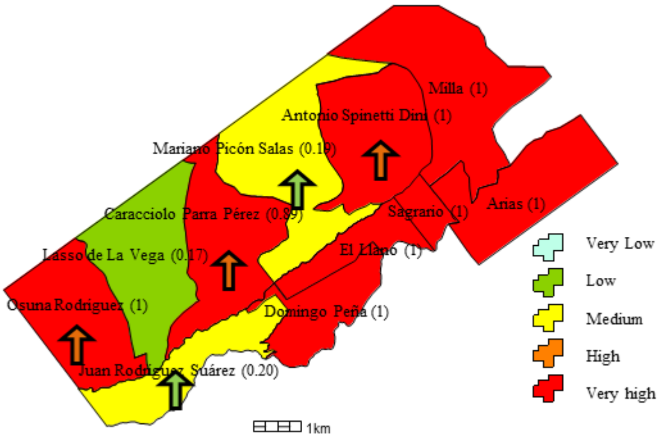


Figure 6. Total seismic risk to intensity IX by parish of the city of Merida, Venezuela (R_T)

4.2 Holistic seismic risk evaluation in Barcelona-Spain

Barcelona is the political and economic capital of Catalonia (Spain), with 1.6million inhabitants and around 71000 buildings and 849700 dwellings according to the official statistics corresponding to the year 2011. It is located in a region considered low to moderate seismicity zone [53]. The historical peak intensities occurred in its territory varied between VI and IX in the EMS-98 scale. There are few recorded acceleration data. The maximum perceived intensity in the city is estimated between VI and VII intensity. The city is organized in 10 districts, of which Ciutat Vella and Eixample are the oldest and show the greatest expected vulnerability and damage [58, 59]. Ciutat Vella means Old City and is the downtown of Barcelona.

4.2.1 Seismic physical risk

Data about seismic physical damages of Barcelona were taken from the technical report [60]. This report shows the results of seismic impact simulations for different scenarios on the buildings and the population of the city, in order to review the Municipal Emergency Action Plan to seismic risk (PAEM, Plan de Actuación de Emergencia Municipal in Spanish). The study was based on the cadastral data of 2008 provided by the Municipal Institute of Computer Science of the City Council of Barcelona. The seismic action was considered in terms of macroseismic intensity (intensity V, VI and VII), according to the European level EMS'98 [45]. The vulnerability of buildings were characterized by the method of level 1, called Vulnerability Index Method [46, 53], developed under the Risk-UE project [4].

The study results are available for each scenario at district and neighborhood scale, among which are: collapse or destroyed areas and human casualties, such an injured and dead people and homeless [60]. Processing these seismic data descriptors we obtained physical damage for the seismic scenarios defined by intensities VI and VII (Figure 7). The possible amplification due to effects soil have not been considered, they should be understood as mean intensities felt in the city in case of earthquake. Physical seismic damage descriptors associated with vital lines were obtained from Lantada et al. [53].

The six descriptors of physical seismic risk, which allowed the quantitative evaluation of the physical seismic risk, were obtained in the case of Barcelona to the intensity VI and VII (Figure 7).

Table 11 shows the values estimated for the physical damage (intensity VII) by district for Barcelona: percentage of damaged area (X_{FR1}), injured people per thousand of inhabitants (‰) (X_{RF2}), dead people (‰) (X_{RF3}), homeless (‰) (X_{RF4}), average damage in the system of potable water (X_{RF5}), and percentage affected of the road system (X_{RF6}). Table 12 shows the obtained values for the physical risk factors based on the damage estimations of Table 11 and the Physical risk index, R_F.

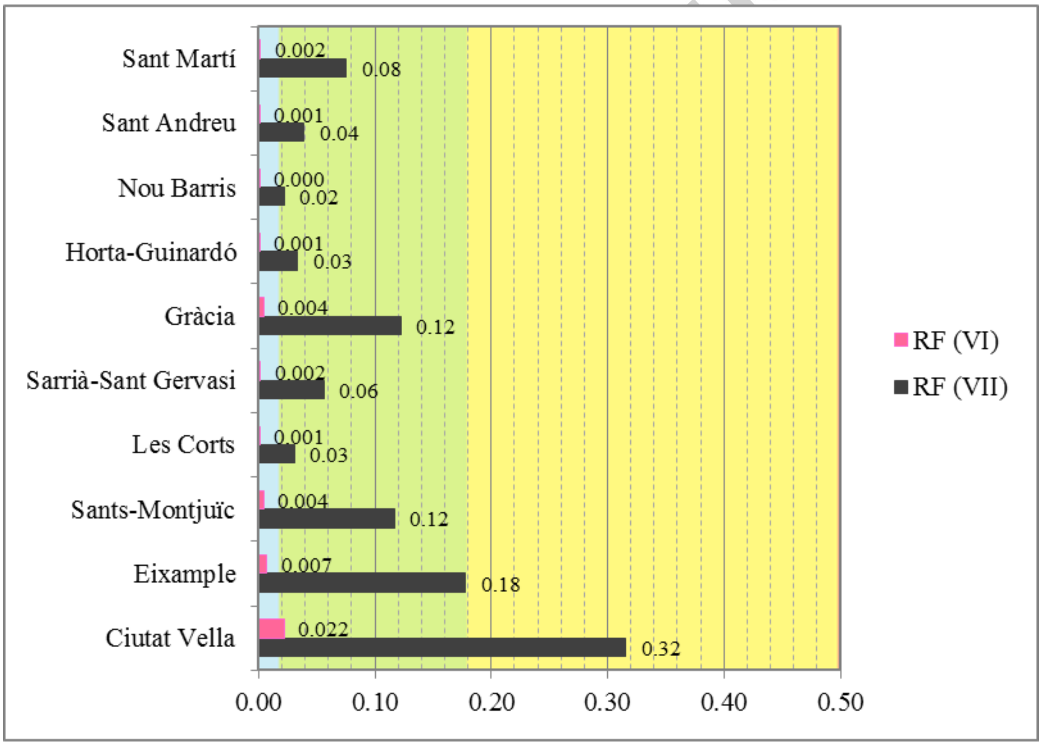
Table 11. Indicators of seismic physical risk for Barcelona (intensity VII)

District	X_{RF1}	X_{RF2}	X_{RF3}	X_{RF4}	X_{RF5}	X_{RF6}
Ciutat Vella	10.90	8.17	2.71	299.41	0.00	0.00
Eixample	7.50	5.36	1.75	178.41	0.00	0.00
Sants-Montjuïc	6.50	3.95	1.29	131.75	0.00	0.00
Les Corts	3.90	2.54	0.79	51.16	0.00	0.00
Sarrià-Sant Gervasi	4.30	3.57	1.13	95.44	0.00	0.00
Gràcia	6.20	4.27	1.39	145.07	0.00	0.00
Horta-Guinardó	3.70	2.55	0.80	65.58	0.00	0.00

Nou Barris	3.10	2.31	0.72	50.69	0.00	0.00
Sant Andreu	4.50	2.67	0.83	54.82	0.00	0.00
Sant Martí	6.20	3.79	1.19	77.34	0.00	0.00

Table 12. Calculated factors of physical risk and Physiscal risk index (intensity VII)

District	F_{RF1}	F_{RF2}	F_{RF3}	F_{RF4}	F_{RF5}	F_{RF6}	R_F
Ciutat Vella	0.59	0.01	0.02	1.00	0.00	0.00	0.32
Eixample	0.28	0.002	0.01	0.67	0.00	0.00	0.18
Sants-Montjuïc	0.21	0.001	0.01	0.39	0.00	0.00	0.12
Les Corts	0.08	0.001	0.002	0.06	0.00	0.00	0.03
Sarrià-Sant Gervasi	0.09	0.001	0.005	0.20	0.00	0.00	0.06
Gràcia	0.19	0.002	0.01	0.47	0.00	0.00	0.12
Horta-Guinardó	0.07	0.001	0.002	0.10	0.00	0.00	0.03
Nou Barris	0.05	0.00	0.002	0.06	0.00	0.00	0.02
Sant Andreu	0.10	0.001	0.003	0.07	0.00	0.00	0.04
Sant Martí	0.19	0.001	0.005	0.13	0.00	0.00	0.08



Risk level	Very low	Low	Moderate	High	Very high
Range	$R_{Fi} \le 0.02$	$0.02 < R_{Fi} \le 0.18$	$0.18 < R_{Fi} \le 0.50$	$0.50 < R_{Fi} \le 0.82$	$0.82 < R_{Fi} \le 1.00$

Figure 7. Seismic physical risk for intensity VI, R_F(VI), and VII, R_F(VII) in the districts of the city of Barcelona, Spain

4.2.2 Social Context

The information to establish prevailing social indicators for Barcelona- Spain, was obtained from local urban observatories, such as Statistical Institute of Catalonia that collects basic statistical information of Barcelona annually [61] and local experts in risk management [62].

Table 13 shows the values of the prevailing social indicators for the districts of the city Barcelona-Spain and the six contributing factors to aggravation, one per category, associated to the prevailing social indicators available are presented in Table 14. These factors allow obtaining the aggravating coefficient (F). It is noted that all city districts have values of aggravation at a Medium level, except the district of Les Corts, with Low level.

Table 13. Values of the prevailing social indicators for the districts of Barcelona

District	Dw2	SD6	UP2	G1	LR1	D1
Ciutat Vella	439.93	96.00	1.50	42.95	3.89	15963.66
Eixample	67.18	96.00	3.00	42.95	5.47	15301.59
Sants - Montjuic	133.35	96.00	3.00	42.95	0.00	7464.94
Les Corts	22.99	96.00	3.00	42.95	8.09	14183.46
Sarrià-Sant Gervasi	142.90	96.00	3.50	42.95	9.01	12867.60
Gràcia	168.85	96.00	3.50	42.95	5.89	17747.33
Horta-Guinardó	92.55	96.00	2.75	42.95	14.35	21908.30
Nou Barris	103.91	96.00	2.00	42.95	0.00	28146.33
Sant Andreu	14.07	96.00	2.15	42.95	0.39	21572.14
Sant Martí	61.29	96.00	2.00	42.95	0.00	21225.32

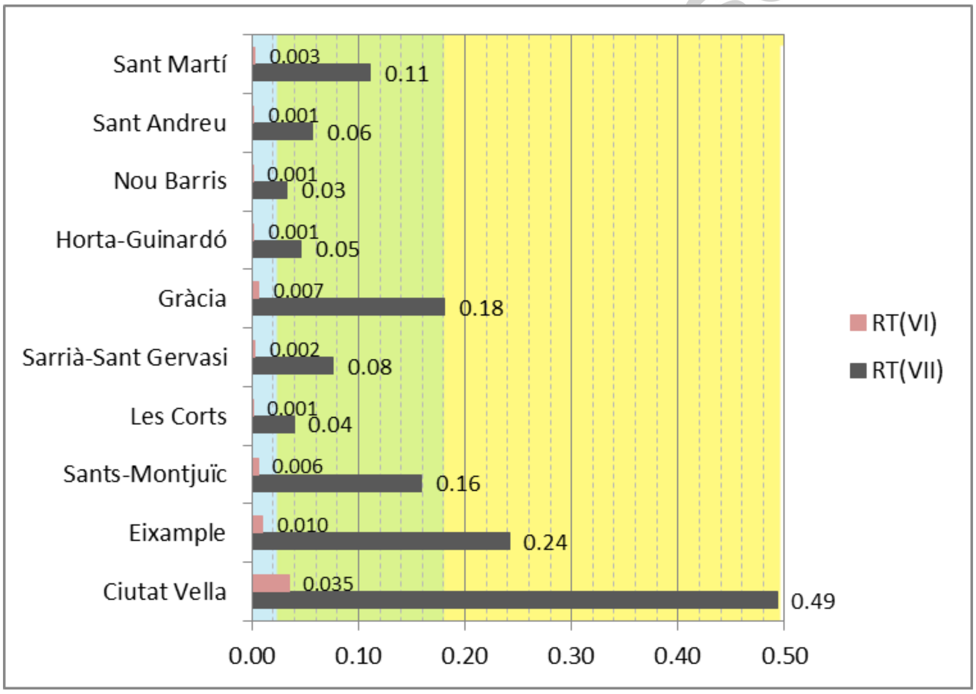
Table 14 Simplified case for calculation of the aggravating coefficient (F) and their components in the districts of the city of Barcelona, Spain

District		Factor associated with social indicator i, F(social indicator i)						Aggravating coefficient (F)	
		F(Dw2)	F(SD6)	F(UP2)	F(G1)	F(LR1)	F(D1)	Value	Level
01	Ciutat Vella	1.000	0.000	0.347	0.557	0.928	0.630	0.561	Medium
02	Eixample	0.100	0.000	0.222	0.557	0.759	0.573	0.357	Medium
03	Sants -Montjuic	0.395	0.000	0.347	0.557	1.000	0.054	0.364	Medium
04	Les Corts	0.012	0.000	0.222	0.557	0.306	0.470	0.284	Low
05	Sarrià-SantGervasi	0.454	0.000	0.347	0.557	0.179	0.357	0.355	Medium

06	Gràcia	0.618	0.000	0.222	0.557	0.697	0.761	0.472	Medium
07	Horta-Guinardó	0.190	0.000	0.222	0.557	0.000	0.957	0.374	Medium
08	NouBarris	0.240	0.000	0.222	0.557	1.000	1.000	0.478	Medium
09	Sant Andreu	0.004	0.000	0.347	0.557	1.000	0.947	0.457	Medium
10	Sant Martí	0.083	0.000	0.347	0.557	1.000	0.935	0.468	Medium

4.2.3 Total Seismic Risk

The total seismic risk for all the districts of Barcelona-Spain increases relative to seismic physical risk for both scenarios (Figure 8). Especially, the districts of Eixample and Gràcia went from Low to Moderate level for the scenario of intensity VII. The remaining districts maintained the same level of seismic physical risk (Ciutat Vella in the Middle level, and the other districts in Low level). For the scenario of intensity VI the total seismic risk level does not change category in relation to the physical risk in any district.



Total risk level	Very low	Low	Moderate	High	Very high
Range	$R_T \leq 0.02$	$0.02 < R_T \leq 0.18$	$0.18 < R_T \leq 0.50$	$0.50 < R_T \leq 0.82$	$0.82 < R_T \leq 1.00$

Figure 8. Total seismic risk for intensity VI, R_T(VI), and VII, R_T(VII) in the districts of the city of Barcelona, Spain

5 Conclusions

The social context can aggravate the physical seismic risk; therefore it is desirable to establish a methodology to evaluate it. Once this estimation is done, it is possible to implement actions to improve the social context, in order not to aggravate the situation that could be generated by an earthquake that interacts with the vulnerability of any urban area.

The proposed methodology for holistic seismic risk assessment improves prior methodologies because their results are standard and easy to interpret (risk has values between 0 and 1). Also, it is expected that necessary social indicators will be easier to obtain because they have been selected from the indicators used by urban observatories of United Nations and other social researchers; such as indicators of the Habitat Agenda (1996) [33], Istanbul+5 (2001) [34], Millennium Development Goals [35] and Carreño [19]. A total of 20 indicators were defined to describe the social context in urban areas. These indicators were classified according to social item they describe, in the following six categories: Dwelling (C1), Social development and Poverty eradication (C2), Urban planning (C3), Governance (C4), Lack of resilience (C5) and Demography (C6).

Applying the determination level analysis thirteen prevailing social indicators are selected: Sufficient living area (Dw1); State of dwelling (Dw2); Poor households (SD5); Literacy Rate (SD6); Growth of informal settlements (UP1); Level urban planning (UP2); Dwellings built in location subject to risk (UP3); Disaster risk management index (G1); Hospital beds (LR1); Human resources in health (LR2); Relief personnel (LR3); Population density (D1); Urban population growth (D2).

In the event that not all information is available for the 13 indicators, the methodology may be simplified by using one social indicator per category. These indicators should be selected based on the determination level analysis as follows: Sufficient living area for C1 category, Poor households (C2), Growth of informal settlements (C3), Disaster risk management index (C4), Hospital beds (C5) and Population density (C6).

In summary, the resolution level for the application of this methodology depends on the available information in the urban area. Therefore, the aggravation coefficient F can be established by: a) General case (n = 13), with the 13 prevailing social indicators or b) Simplified case by only six predominant indicators (n = 6), one for each category and higher level of determination. Obviously, according to available information of the case of study the number of indicators could be between 6 and 13.

The proposed standard methodology for estimating the coefficient of aggravation (F) in urban areas has been applied to the city of Merida in Venezuela and the European city of Barcelona in Spain. In both cities, this methodology was easy to apply, despite being two cities with very different characteristics and available information. Urban observers in both cities allowed to establish data required for simplified case (six predominant social indicators). In the case of Merida the methodology was also apply by using 11 indicators. Therefore, the proposed methodology to measure the social context is easy to adapt to study of different urban areas.

In both cities the same social indicators were used for categories C3 to C6: level of urban planning, disaster risk management index, hospital beds and population density, respectively. For category C1 Sufficient living area was used for Merida and State of dwelling for Barcelona; and in the case of C2: Poor households was used for Merida and Literacy rate for Barcelona. In both cities the Disaster risk management index (G1) showed an appreciable level of performance [22].

The results for Merida had on average a higher contribution to the aggravating factor (F) from hospital beds, disaster risk management index and level of urban planning, compared to the contribution in Barcelona. The contribution of population density indicator to F in Merida had lower values than Barcelona.

The physical seismic risk in the city of Barcelona was on average very low for the scenario of intensity VI and low for the intensity VII. While in Merida it was low and high for the scenarios of intensity of VIII and IX, respectively. A similarity was observed in the level of aggravation coefficient in both cities (moderate level). Finally, the average values of total seismic risk (R_T) in both cities were moderate and very high in the city of Merida for scenarios of intensities VIII and IX, respectively; and very low and low in Barcelona for the scenarios of intensities of VI and VIII, respectively.

Despite the similarity in the level of aggravation coefficient, the social context of each city would affect the physical seismic risk in a different way in the scenarios with high intensities. Barcelona would not be affected significantly by the social context, since in most districts (eight of ten) the level of total seismic risk remained the same level of physical seismic risk (R_{Fi}) for the intensity VII. While the social context in Merida would significantly worsen the physical seismic risk, since in five of the eleven parishes, the total seismic risk goes up a level with respect to R_{Fi} level for intensity IX.

6 References

[1] ATC-13 (1985). Earthquake damage evaluation data for California, ATC-13. Redwook City, California: Applied Technology Council. 492.

[2] RADIUS (2000). Risk Assessment tools for DIagnosis of Urban areas against Seismic Disasters. http://www.geohaz.org/projects/radius.html. Accessed 30 Setember 2010

[3] FEMA. (1999). Earthquake loss estimation methodology. HAZUS-99 Technical manual. Federal Emergency Management Agency. Washington, D.C.

[4] Mouroux, P., Bertrand, E., Bour, M., Brun, B. l., Depinois, S., and Masure, P. (2004). The european Risk-UE project : an advanced approach to Earthquake risk scenarios. Vancouver, B.C., Canada: 13th World Conference on Earthquake Engineering. http://www.iitk.ac.in/nicee/wcee/article/13_3329.pdf. Accessed 28 Setember 2010

[5] Calvi, G.M. and Pinho, R. (2004). "LESSLOSS. A European Integrated Project on Risk Mitigation for Earthquakes and Landslides", Report 2004/02, European School for Advanced Studies in Reduction of Seismic Risk (ROSE School), ISBN: 88-7358-020-3 Pavia, Italy.

[6] Pitilakis, K., Crowley H., Kaynia, A.M., (2014) SYNER-G: Typology Definition and Fragility Functions for Physical Elements at Seismic Risk. Springer. Geotechnical, Geological and Earthquake Engineering. Volume 27 2014. ISBN: 978-94-007-7871-9 (Print) 978-94-007-7872-6 (Online)

[7] UPStrat-MAFA (2012) UPStrat-MAFA (2012) Urban disaster prevention strategies using MAcroseismic Fields and Fault Sources (UPStrat-MAFA – EU Project Num. 230301/2011/613486/SUB/A5), DG ECHO Unit A. http://upstrat-mafa.ov.ingv.it/UPStrat/ Accessed 1 April 2016

[8] Silva V, Crowley H, Pagani M, Monelli D, Pinho R (2014) Development of the OpenQuake engine, the Global Earthquake Model's open-source software for seismic risk assessment. Nat Hazards 72:1409–142 doi:10.1007/s11069-013-0618-x

[9] CAPRA (2012). CAPRA Probabilistic Risk Assessment Initiative. http://www.ecapra.org Accessed 27 July 2012

[10] Cardona, O. D., Ordaz, M., Yamin, L., and Barbat, A. (2011). Enfoque integral para la evaluación probabilista del riesgo (CAPRA): Iniciativa internacional para la efectividad de la gestión del riesgo de desastre. 4 ° Congreso Nacional de Ingeniería Sísmica (4CNIS). Granada, España.

[11] Jaramillo, N. (2014). Evaluación holistica del riesgo sísmico en zonas urbanas y estrategias pra su mitigación. Aplicación a la ciudad de Merida-Venezuela. Barcelona: Universidad Politécnica de Cataluña. Tesis Doctoral.

[12] Birkman, J., Cardona, D. O., Carreño, M. L., Barbat, A. H., Pelling, M., Schneiderbauer, S., Welle, T. (2013). Framing vulnerability, risk and societal responses: the MOVE framework. Natural Hazards, 67: 193-211.

[13] Roberts, N. J., Nadim, F., and Kalsnes, B. (2009). Quantification of vulnerability to natural hazards. Georisk: Assessment and Management of Risk for Engineered Systems and Geohazards, 3(3), 164-173. DOI: 10.1080/17499510902788850.

[14] de Oliveira, M. J. (2009). Social vulnerability indexes as planning tools: beyond the preparedness paradigm. Journal of Risk Research, 12(1), 43-58.

[15] Birkmann, J. (2006). Measuring Vulnerability to Natural Hazards: Towards disaster resilient societies. Tokyo, Japan: United Nations University, Institute for Environment and Human Security, UNU-EHS.

[16] Villagrán De León, J. C. (2006). Vulnerability A Conceptual and Methodological Review. Bonn,Germany: United Nations University, Institute for Environment and Human Security, UNU-EHS. Nº 4.

[17] Cardona, O. D. (2001). Estimación holística del riesgo sísmico utilizando sistemas dinámicos complejos. Tesis Doctoral, Universidad Politécnica de Cartaluña, Barcelona.

[18] Cutter, S. (1996). Vulnerability to enviromental hazard. Progress in Human Geography, 20(4), 529-539.

[19] UN-Habitat. (2009). UN-HABITAT del mundo.

http://www.onuhabitat.org/index.php?option=com_docman&task=cat_view&gid=74&Itemid=71. Accessed 1 February 2014

[20] Cardona, O. D. (2005). Sistema de indicadores para la gestion de riesgo de Desastres: programa America Latina y el Caribe. Informe Técnico principal. Manizales, Colombia: Instituto de Estudios Ambientales IDEA. Universidad Nacional de Colombia.

[21] Carreño, M. L., Cardona, O. D., and Barbat, A. H. (2004). Metodología para la evaluación del desempeño de la gestión de riesgo. Barcelona: Monografías CIMNE, Universidad Politécnica de Cataluña.

[22] Carreño, M. L., Cardona, O. D., and Barbat, A. H. (2007). A disaster risk management performance index. Natural Hazards, 41(1), 1-20.

[23] Carreño, M. L. (2006). Técnicas innovadoras para la evaluación del riesgo sísmico y su gestión en centros urbanos: Acciones ex ante y ex post. Tesis Doctoral, Universidad Politécnica de Cataluña, Barcelona.

[24] Carreño, M. L., Cardona, O. D., and Barbat, A. H. (2007). Urban seismic risk evaluation: a holistic approach. Natural Hazards, 40(1):137–172.

[25] Barbat, A.H., Carreño, M.L., Cardona, O.D., Marulanda, M.C.(2011). Holistic assessment of seismic risk in urban areas. Revista Internacional de Metodos Numericos para Calculo y Diseño en Ingenieria 27(1):3-27.

[26] Marulanda, M.C., Cardona, O.D., & Barbat, A.H. (2009). Robustness of the holistic seismic risk evaluation in urban centers using the USRi. Natural Hazards, 49, 501–516

[27] Fernandez, J., Mattingly, S., Bendimerad, F., & Cardona, O. (2006). Application of indicators in Urban and megacities disaster risk management, a case study of Metro Manila, EMI Topical Report TR- 07-01, September 2006, 30 p.

[28] Khazai B, Kilic O, Basmaci A, Konukcu B, Sungay B, Zeidan A, Wenzel F (2008) Megacity indicators system for disaster risk management-implementation in Istanbul, Megacity Istanbul Project Reports Municipality Disaster Management Center (AKOM), Istanbul, Turkey

[29] Carreño, M. L., Cardona, O. D., and Barbat, A. H. (2012). New methodology for urban seismic risk assessment from a holistic perspective. Bulletin of earthquake engineering 10(2) 547-565. Springer Netherlands.

[30] Carreño, M. L., Barbat, A. H., Cardona, O. D. (2014). Numerical method for the holistic evaluation of the seismic risk based on the fuzzy sets theory. Revista internacional de metodos numericos para calculo y diseno en ingenieria 30(1):25-34.

[31] Cutter, S. L., Boruff, B. J., and Shirley, L. W. (2003). Social Vulnerability to Environmental Hazards. Social Science Quarterly, 84(2), 242-261. DOI: 10.1111/1540-6237.8402002.

[32] Padrós, L. (2008). Indicadors urbans per a un observatori urbà associats a la millora de barris a Yaoundé. Tesina, UPC, Infraestructura de transporte y territorio.

[33] Habitat Agenda (1996). United Nations Conference on Human Settlements (Habitat II) in Istanbul, Turkey from 3 to 14 June 1996. http://www.un-documents.net/hab-ag.htm

[34] Istanbul+5 (2001). Istanbul+5: United Nations Centre for Human Settlements (Habitat). General Assembly, Special Session for an overall review & appraisal of the implementation of the Habitat Agenda. New York, 6-8 June 2001. http://www.un.org/ga/Istanbul+5/

[35] MDGs (2008). The Millennium Development Goals Report. Department of Economic and Social Affairs of the United Nations Secretariat. Available at: http://www.un.org/millenniumgoals/2008highlevel/pdf/newsroom/mdg%20reports/MDG_Report_2008_ENGLISH.pdf

[36] Saaty, T. (1980). The Analytic Hierarchy Process. New York: McGraw-Hill.

[37] MOP. (1976). Microzonificación sísmica de la meseta de Mérida (Vol. I y II). Caracas, Venezuela: Publicaciones Técnicas, Ministerio de Obras Públicas, Dirección Generalde Desarrollo Urbanístico, Secretaría Técnica.

[38] Gutiérrez, J. (2008). Actualización del mapa geológico del área metropolitana de Mérida-Venezuela. The 33rd IGC International Geological Congress, Oslo, Norway. 6-14 August, 2008.

[39] Rebotier, J. (2006). Método de localización de los heridos en el caso de un terremoto en la ciudad de Merida, Venezuela. Revista Geográfica Venezolana, 47, 187-200.

[40] Castillo, A. (2005). Seismic risk scenarios for buildings in Merida, Venezuela. Detailed vulnerability assessment for non-engineered housing. Tesis Doctoral, Universidad Politécnica de Cataluña, Barcelona. http://hdl.handle.net/10803/6537

[41] Alcaldía de Merida (2002). Gaceta Municipal. Merida. Depósito Legal Nro. 79-0151 Extraordinaria Nro.58 Año III: Consejo Municipal. Municipio Libertador

[42] COVENIN (2001). Edificaciones Sismorresistentes. Norma COVENIN 1756:2.001. Venezuela.

[43] Funvisis (2000) Mapa de fallas cuaternarias de Venezuela. http://www.funvisis.gob.ve/archivos/mapas/fallas_activas.pdf. Accessed 29 October 2015

[44] Laffaille, J., and Ferrer, C. (2003). El terremoto del jueves santo en Merida: año 1812. Revista Geográfica Venezolana, 44(1), 107-123.

[45] Grünthal, G. (1998). European Macroseismic Scale 1998, vol. 15. Luxemburg: Centre Européen de Géodynamique et Séismologie, Cahiers du Centre Européen de Géodynamique et de Séismologie.

[46] Milutinovic, Z. V., and Trendafiloski, G. S. (2003). WP04. Vulnerability of current buildings. RISK-UE project: An advanced approach to earthquake risk scenarios with applications to different European towns. Contract No.EVK4-CT-2000-00014. Institute of Earthquake Engineering and Engineering Seismology (IZI), Skopje. No. of pages 110 (Figs. 18, Tables 48, Appendices 2).

[47] Laffaille, J. (1996). Escenario Sísmico de la ciudad de Merida. Tesis de Maestía, Instituto de Estadística Aplicada y Computación F.A.C.E.S. Universidad de Los Andes, Merida, Venezuela.

[48] Castillo, A, López-Almansa, L., Pujades L.G. (2011) Seismic risk analysis of urban non-engineered buildings: application to an informal settlement in Merida,Venezuela. Natural Hazards, 59:891–916. DOI 10.1007/s11069-011-9805-9

[49] Lantada, N. (2007). Evaluación del riesgo sísmico mediante métodos avanzados y técnicas GIS. Aplicación a la ciudad de Barcelona. Tesis Doctoral, Universidad Politécnica de Cataluña, Dpto. de Ingeniería del terreno cartográfica y geofísica, Barcelona. Accessed 25 November 2015 http://www.tdx.cat/handle/10803/6259

[50] Astorga, A. L. (2011). Resiliencia sísmica del sistema de acueducto para la ciudad de Merida. Merida: Centro interamericano de desarrollo e investigación ambiental y territorial. ULA.

[51] Coburn, A., and Spence, R. (1992). Earthquake Protection. Chinchester: Jonh Wiley & Sons.

[52] Vacareanu, R., Lungu, D., Aldea, A., and Arion, C. (2004). WP7 Report Seismc Risk Scenarios Handbook. No. of pages 50 (Figs. 14, Tables 8, Appendices 2).

[53] Lantada N., Irizarry J., Barbat A.H., Goula X., Roca A., Susagna T., Pujades L.G. (2010) Seismic hazard and risk scenarios for Barcelona, Spain, using the Risk-UE vulnerability index method. Bull Earthquake Eng (2010) 8:201–229. DOI 10.1007/s10518-009-9148-z

[54] INE. (2001). Instituto nacional de estadistica dela República Bolivariana de Venezuela. Recuperado el 2010 de Agosto de 20, de Censo 2001 de Venezuela: http://www.ine.gov.ve/

[55] INGEOMIN. (2010). Estudio de susceptibilidad ante movimientos en masa aplicado a la poligonal urbana del municipio libertador, Estado Merida 2009-2010. Instituto Nacional de Geología y Minería. Proyecto Gestión Integral de Riesgo en Espacios Urbanos, Municipio Libertador, Estado Merida, Merida.

[56] Ramírez, N. d., and Saito, S. M. (2011). Zonificación de áreas susceptibles a los movimientos en masa: terraza de la Ciudad de Merida y sus alrededores. Anais XV Simpósio Brasileiro de Sensoriamento Remoto - SBSR-, (pp. 4609-4616). Curitiba, PR, Brasil.

[57] SIGRA (2008). Sistema de Información Geográfica de la Región de Los Andes (SIGRA): Dossier 2008 Municipio Libertador Merida. Merida-Venezuela: CORPOANDES.

[58] Lantada, N., Pujades, L. G., and Barbat, A. H. (2009). Vulnerability index and capacity spectrum based methods for urban seismic risk evaluation. A comparison. Natural Hazards, 51:501–524. DOI 10.1007/s11069-007-9212-4

[59] Barbat, A.H., Carreño, M.L., Pujades, L.G., Lantada, N, Cardona, O.D., Marulanda, M.C. (2010). Seismic vulnerability and risk evaluation methods for urban areas. A review with application to a pilot area. Structure and Infrastructure Engineering 6(4): 499-499. DOI: 10.1080/15732479.2010.481841.

[60] Lantada, N., Pujades, L. G., and Barbat, A. H. (2009). Escenarios de riesgo sísmico para la Barcelona. Pla d'Actuació d'Emergència Municipal (PAEM) en cas de sisme" en coordinación con el Plan de Emergencia SÍSmica de CATaluña (SISMICAT). Barcelona: UPC.

[61] IDESCAT (2010). IDESCAT, Institut d'Estadística de Catalunya. (Generalitat de Catalunya). http://www.idescat.cat/ Accessed 6 July 2012

[62] Carreño, M. L., Barbat, A. H., Cardona, O. D., and Marulanda, M. C. (2014). Holistic Evaluation of Seismic Risk in Barcelona, en Assessment of vulnerability to Natural Hazards: A European Perspective. Edited by: Alexander D., Birkmann J., Kienberger S. Editorial.