# Assessment of Vulnerability to Natural Hazards

## A European Perspective



Edited by

Jörn Birkmann, Stefan Kienberger and David E. Alexander

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Chapter 2

# Holistic Evaluation of Seismic Risk in Barcelona

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**Chapter Outline**



## 2.1 INTRODUCTION

This chapter shows the case study of Barcelona; here the seismic risk of the city is studied by applying a probabilistic analysis of the hazard and risk. On this basis a holistic evaluation of risk is performed taking into account social fragility and lack of resilience aspects. Finally, a complementary evaluation of the disaster risk management performance is conducted.

## 2.2 DESCRIPTION OF THE CITY

The city of Barcelona was founded by the Romans, as a result of the campaigns against the Carthaginian general Hannibal Barca during the Punic Wars. At the end of the Roman period, the city had nearly 12,000 inhabitants. By

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the end of the fourth century, Barcelona was a fortified, walled town, covering about 10.5 Ha. Barcelona's evolution into a big city began in 1868 when adjacent, independent towns were incorporated as city districts. Between 1910 and 1930, the population grew from 587,411 to 1005,565 inhabitants. This population explosion was accompanied by a highly productive construction period. The city of Barcelona, capital of Catalonia and second largest city of Spain, has a total of 1621,537 inhabitants (2009) and is located on the northeast coast of Spain (Figure 2.1). Bounded by the Collserola ridge and rivers Besós and Llobregat, the city has an area of almost 100 $km^2$ and a population density over 16,215 persons/$km^2$. Barcelona is a leading tourist, economic, trade fair/exhibitions and cultural-sports center in Spain.

Nowadays, Barcelona has 10 administrative districts: Ciutat Vella, Eixample, Sants-Montjuïc, Les Corts, Sarrià-Sant Gervasi, Gràcia, Horta-Guinardó, Nou Barris, Sant Andreu, and Sant Martí. This division of the city is based on the historic evolution of the city. Ciutat Vella is the old center of the city and the Eixample is where the city expanded after the city walls were knocked down. The other districts correspond to municipal areas which appeared around the old city, outside the walls, and which became part of Barcelona during the nineteenth and twentieth centuries. The districts are subdivided into 73 neighborhoods and 235 AEBs (basic statistic areas in Spanish). According to the cadastral information,[1] there are 70,655 buildings in the city.

## 2.3 LOCAL SEISMIC HAZARD

Due to the high population growth, most part of the city's building stock was constructed when no seismic-resistant construction codes were required. The combination of very old buildings made of nonreinforced masonry and constructed without seismic requirements and a highly populated and active urban area can be extremely risky even under the effects of a moderate earthquake.

The seismicity of the Catalonia region is moderate compared to other regions along the Mediterranean Sea area. The fourteenth and fifteenth centuries were seismically active centuries; several earthquakes caused major damages in Barcelona (1373, 1410, 1427, 1428 and 1448). On February 2, 1428, an earthquake with the epicenter located in the Pyrenees with a local magnitude of 6.5 and an epicenter distance of 90 km damaged slightly some churches at Barcelona. This earthquake caused great damage to many houses and pulled down the rose window of Santa Maria de la Mar, and killed 16 people. In 1448, another earthquake with a local magnitude of 5.5 caused major damage to many properties both inside and outside the city. In the capital, it damaged Castell Nou producing a

1. Cadastal information was provided in 2009 by the Subdirecció d' Informació Cartogràfica i de Base, S.A. (ICB) (antes llamada Centre de Cartografia Automàtica, CCA), del Instituto Municipal de Informàtica del Ayuntamiento de Barcelona.


**FIGURE 2.1** Location of the city of Barcelona.

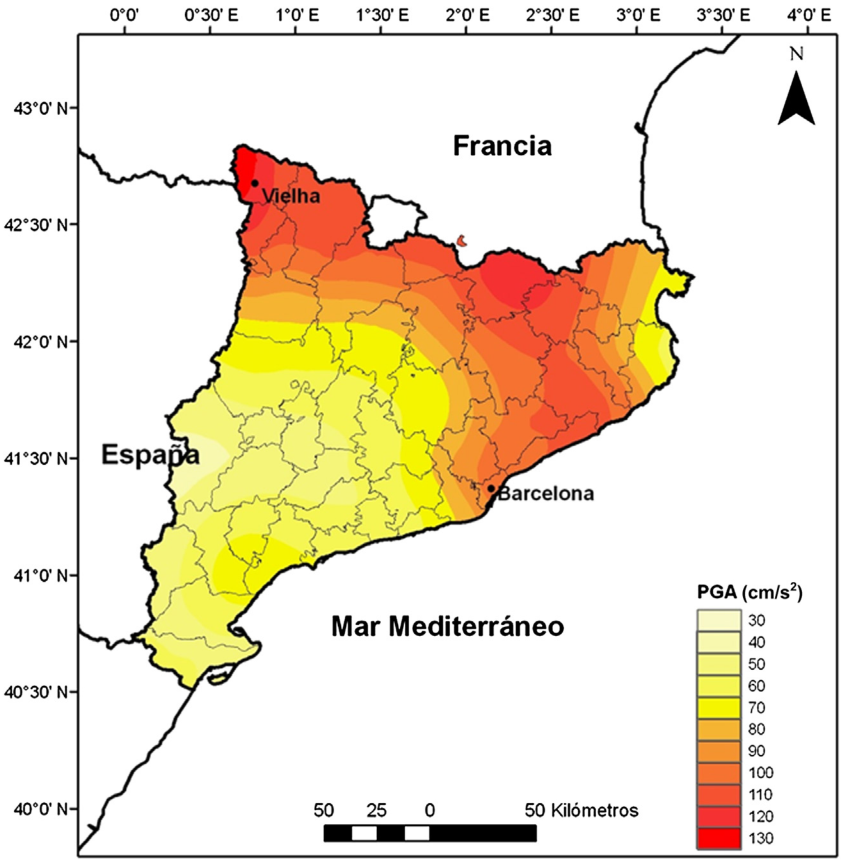



**FIGURE 2.2** Seismic hazard map for 475 years of return period (GEOTER, 2008).

crack through which a man could easily pass. During the twentieth century, a few earthquakes had been felt in the city with a maximum intensity of IV degrees in the MSK intensity scale.

Various earthquakes struck Barcelona—and Catalonia—in the last third of the fourteenth century and the first half of the fifteenth century, which had a great effect on the collective memory compared to the actual damage (Egozcue et al., 1991). More recently, small earthquakes occurred (i.e., Mw:4.6 on May 15, 1995 and Ml: 4.0 on September 21, 2004), but without causing damage to people and buildings in the city. Figure 2.2 is a seismic hazard map of Catalonia which shows the peak ground accelerations (PGA) estimated for a 475 years return period. The seismic hazard has been simulated for Catalonia by using the system CRISIS 2007 (Ordaz, 2007) which is part of the platform ERN-CAPRA. CRISIS 2007 allows calculating the seismic hazard associated with all the feasible events, a group of selected events, or even a single relevant event, providing the probable maximum intensity for different occurrence rates or return period.

## 2.4 METHODOLOGY OF SEISMIC RISK ASSESSMENT

A probabilistic evaluation of the seismic risk has been done, including the probabilistic analysis of the seismic hazard which can affect Barcelona and of the seismic physical vulnerability of the buildings of the city. This evaluation involves the probabilistic calculation of both the seismic hazard and the vulnerability (Marulanda et al., 2013).

Parameters such as the frequency of occurrence of a given earthquake, the probability that it will occur at a specific site, the exceedance probabilities of the seismic intensities, etc., are included in the calculation models, in order to perform a probabilistic seismic hazard analysis (PSHA). The steps to be followed to apply PSHA are:

1. The characterization of the seismic sources generating earthquakes with influence on the study area, in terms of the geometry and the probability distribution of the points where the fault rupture starts. It is usual to assume a uniform probability distribution, which implies that the occurrence of an earthquake can be expected with the same probability in any point of the geometry of the defined source.
2. Determination of seismicity of the considered sources, based on historical records of events occurring in the defined geometry (seismic catalog), and on information and studies of neo-tectonics and paleo-seismology for the source. Seismicity is established through magnitude recurrence curves.
3. Selection of attenuation functions which will allow the hazard at the site to be completely characterized. Depending on the scope of the analysis, attenuation functions will be required for acceleration, velocity, displacement, spectral components of these parameters, duration, etc.
4. Finally, the uncertainties associated with location, size, and attenuation are combined, and a hazard code is obtained. This indicates the probability that a specific intensity may be equaled or exceeded in a given period of time.

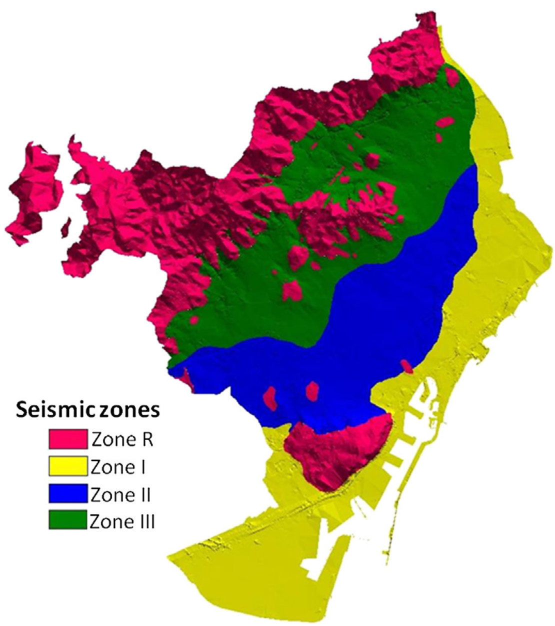
The application to Barcelona takes into account the seismic sources identified by Secanell (2004) for the Catalonian region of Spain. Additionally, attenuation effects of the seismic waves were also considered in the mentioned reference by means of probabilistic spectral attenuation laws that include different source types and the local amplification effects based on microzonation studies (Ambraseys et al., 1996).

The seismic hazard is quantified in terms of return periods (or its inverse, the exceedance rates) of the relevant seismic intensities for the behavior of the structures. The exceedance rate of a seismic intensity is defined as the average number of times, per unit of time, in which the value of the seismic intensity is exceeded.

A series of stochastic events are simulated for the probabilistic risk analysis. These events represent the effects of all the possible earthquakes at any location and magnitude in the area of influence. The set of scenarios generated must represent all the hypocenter and the whole possible magnitudes associated with each hypocentral location. Each of these events or scenarios is associated with a specific occurrence frequency. The scenarios associated with earthquakes of minor magnitude have a greater probability of occurrence, while the scenarios associated with larger earthquakes have a relatively low probability of occurrence.

The probabilistic calculation method evaluates the desired risk parameters such as percentages of damage, economic losses, effects on people and other effects, for each of the hazard scenarios and then these results are probabilistically integrated by using the occurrence frequencies of each earthquake scenario. In Barcelona, 2058 seismic hazard scenarios have been generated by using the CAPRA platform.

Site effects are included to consider the amplification of seismic hazard parameters according to the geological characterization of Barcelona (Cid et al., 2001) (see Figure 2.3). Each zone is characterized by a transfer function and an amplification factor for the acceleration level on the rock. They are four zones: Zone I, Holocene deposits which include sand, silt, pebbles and organic matter; Zone II, Pleistocene deposits composed of clay, silt, gravel and calcareous crusts; Zone III, Paleozoic materials mainly granite, slate, limestone,




| Soil zone | Vs (m/s) | Eurocode subsoil class |
|---|---|---|
| R | 225 | C |
| I | 384 | B |
| II | 405 | B |
| III | 800 | A |

**FIGURE 2.3** Seismic zonation based on local effects (Cid et al., 2001).

interbedded quartzite, sandstone and metamorphic rocks; and the Zone R corresponds to rock.

The *exposure* is mainly related to the infrastructure components or exposed population which can be affected by a particular event. To characterize the exposure, it is necessary to identify the individual components, including their location, main physical, geometric and engineering characteristics, their vulnerability to hazardous events, their economic value and the level of human occupation. The exposure value of the assets at risk is usually estimated from secondary sources such as available databases.

This study uses information of Barcelona compiled by Lantada (2007). The economic value of the exposed elements was supplied by the Cadastral Office of Barcelona in 2009, and they were 70,655 buildings taken into account. For each building, the geographic situation, economic value, year of construction, number of levels, structural type and human occupation were defined. Figure 2.4 shows the exposed value (in Euros) of the AEBs of Barcelona.

The *vulnerability* of the buildings in the city has been defined by vulnerability functions using the Vulnerability Module of the ERN-CAPRA platform starting from capacity curves defined in the previous studies performed in the RISK-UE project (ICC/CIMNE, 2004; Lantada et al., 2009, 2010; Irizarry et al., 2011). These functions are defined for each building typology; the most common structural system used in Barcelona is the unreinforced masonry, followed by the reinforced concrete, whose construction has increased rapidly in recent decades. Wood and steel structures are less used and these buildings are not usually for residential use but for industrial or other uses such as markets and sports areas among others. The used typologies were defined in ICC/CIMNE (2004) and are shown in Table 2.1, and were the masonry which is the most frequent building typology.

Each structural type is subdivided into three classes according to the height:

- Low height, L: one to two floors for masonry and wood structures; and one to three floors for reinforced concrete and steel buildings.
- Medium height, M: three to five floors for masonry and wood structures; and four to seven floors for reinforced concrete and steel buildings.
- High altitude, H: six or more floors for masonry and wood structures; and eight or more floors for reinforced concrete and steel buildings.

The vulnerability functions used are shown in Figure 2.5, for the unreinforced masonry buildings; and in Figure 2.6 for the rest of the building typologies. These vulnerability curves are relating spectral acceleration with mean damage ratio, but also include the standard deviation.

The physical seismic risk is evaluated by means of the convolution of the hazard with the vulnerability of the exposed elements and the results are the potential effects or consequences. Risk can be expressed in terms of damage or physical effects, absolute or relative economic loss and/or effects on the population. Once the expected physical damage has been estimated (average potential value and its

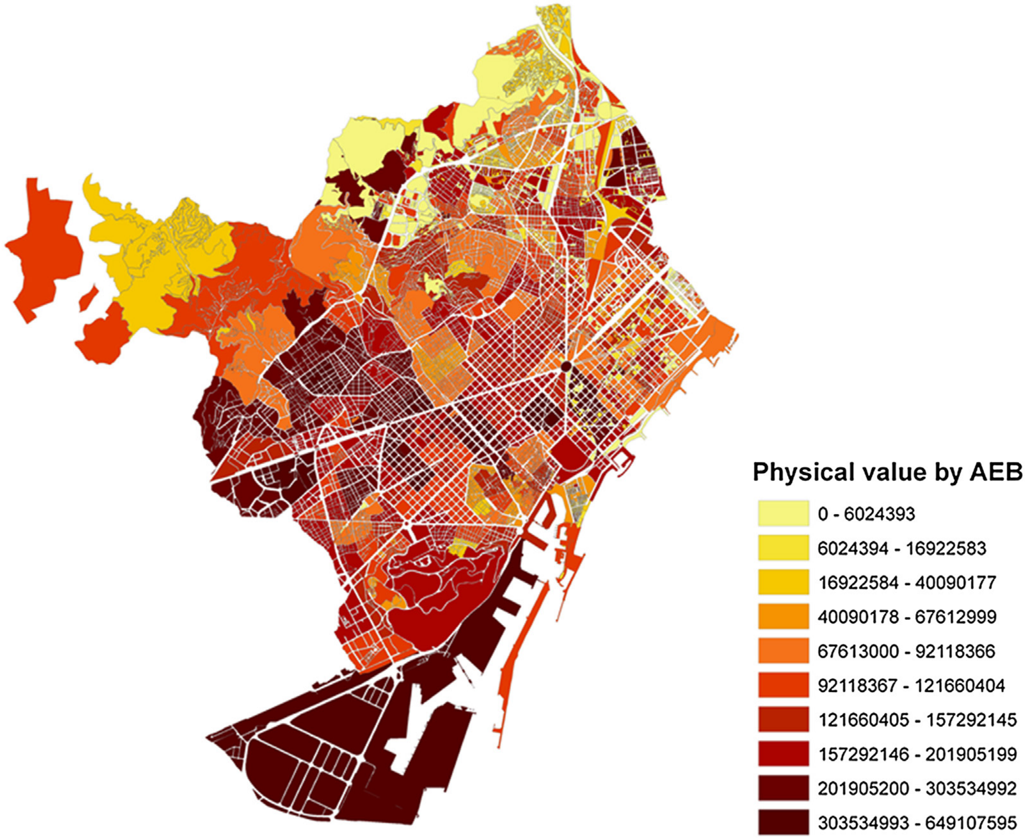



**FIGURE 2.4** Exposed value of the AEBs of Barcelona.

**TABLE 2.1 Building Typology Matrix for Barcelona (ICC/CIMNE, 2004)**

| | | |
|---|---|---|
| Unreinforced masonry | M3.1 | Unreinforced masonry bearing walls with wooden slabs |
| | M3.2 | Unreinforced masonry bearing walls with Masonry vaults |
| | M3.3 | Unreinforced masonry bearing walls with composite steel and masonry slabs |
| | M3.4 | Reinforced concrete slabs |
| Reinforced concrete | RC3.1 | Concrete frames with unreinforced masonry infill walls with regularly infill frames |
| | RC3.2 | Concrete frames with unreinforced masonry infill walls with irregularly frames (i.e., irregular structural system, irregular infill, soft/weak storey) |
| Steel moment frames | S1 | A Frame of steel columns and beams |
| Steel braced frames | S2 | Vertical components of the lateral force-resisting system are braced frames rather than moment frames |
| Steel frames with unreinforced masonry infill walls | S3 | The infill walls usually are offset from the exterior frame members, wrap around them, and present a smooth masonry exterior with no indication of the frame |
| Steel and RC composite systems | S5 | Moment resisting frame of composite steel and concrete columns and beams. Usually the structure is concealed on the outside by exterior nonstructural walls |
| Wood structures | W | Repetitive framing by wood rafters or joists on wood stud walls. Loads are light and spans are small |

dispersion) as a percentage for each of the assets or infrastructure components included in the analysis, one can make estimates of various parameters useful for the proposed analysis as the result of obtaining the Loss Exceedance Curve (LEC).

Loss Exceedance Curve, LEC, represents the annual frequency of exceedance of a specific loss. This is the most important catastrophe risk metric for risk managers, since it estimates the amount of funds required to meet risk management objectives. The LEC can be calculated for the largest event in one year or for all (cumulative) events in one year. For risk management purposes, the latter estimate is preferred, since it includes the possibility of one or more severe events resulting from earthquakes. Once calculated the Loss Exceedance Curve, it is possible to obtain other appropriate metrics for the financial analysis of the losses such as the Average Annual Loss or Pure Risk Premium for each building and for sets of buildings. The Probable Maximum Loss is obtained for the whole portfolio, that is, the entire city (Ordaz et al., 2003; Cardona et al., 2008).

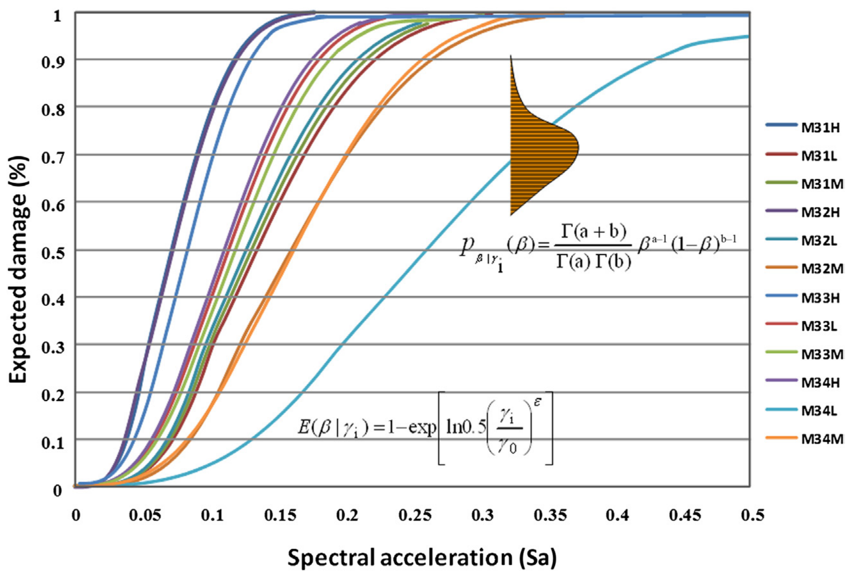



**FIGURE 2.5** Vulnerability functions for unreinforced masonry buildings.

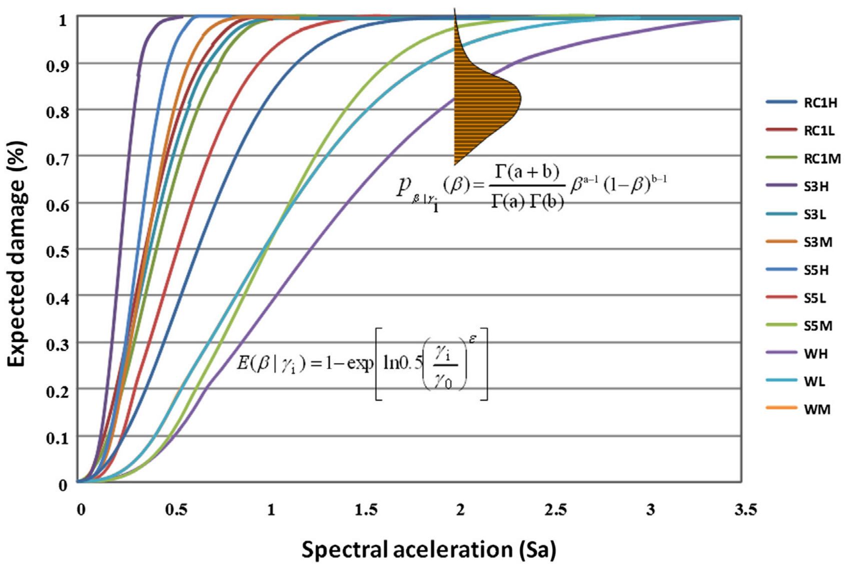



**FIGURE 2.6** Vulnerability functions for reinforced concrete, steel, and wood buildings.

Average Annual Loss, AAL, is the expected loss per year. Computationally, AAL is the sum of the product of the expected losses in a specific event and the annual occurrence probability of that event, for all stochastic events considered in the loss model. The expected annual loss considers the losses of each building for all the events that can occur; supposing that the process of occurrence of hazard events is stationary and that damaged structures have their resistance immediately restored after an event (Ordaz et al., 1998; Ordaz and Reyes, 1999).

The annual occurrence frequency of events depends on the results of hazard assessments. The loss expected value, given the occurrence of a particular event, depends on the vulnerability of the exposed element.

Probable Maximum Loss, PML, represents the loss amount for a given annual exceedance frequency, or its inverse, the return period. Generally, the PML, in economic value or in percentage with regard to the return period, specifies the PML curve. The PML of an exposed base is an appraiser of the size of maximum losses reasonably expected in a set of elements exposed during the occurrence of a hazard event. Typically, PML is a fundamental data to determine the size of reserves that, for example, insurance companies or a government should maintain to avoid excessive losses that might surpass their adjustment capacity.

The Average Annual Loss for physical assets, fatalities and injuries are calculated for each building of the city. The probabilistic results for the city of Barcelona are shown in Tables 2.2–2.4; the expected annual loss is given in economic value per 1000, the number of persons is per 100,000 population and the Probable Maximum Loss (PML) values for different return periods. Figure 2.7 shows the PML curve obtained for Barcelona. Figure 2.8 shows the expected annual loss for each AEB of Barcelona. As it was previously mentioned, the expected annual loss was originally calculated building by building and Figure 2.9 shows the obtained results at this resolution. From Figure 2.8 can be seen how the expected annual loss values are highest in the old part of the city. More information about the seismic risk for the city of Barcelona can be found in Barbat et al. (2010) and additional information about a probabilistic seismic risk evaluation can be seen in Marulanda et al. (2013).

## 2.5 HOLISTIC RISK EVALUATION

A holistic evaluation of the disaster risk has been performed by adapting the methodology proposed by Carreño (2006) and Carreño et al. (2007a) and into the frame of the conceptual framework of the MOVE project (Birkmann et al., 2013). In this methodology, risk requires a multidisciplinary evaluation that takes into account not only the expected physical damage, the number and type of casualties, or economic losses (first order impact), but also the conditions related to social fragility and lack of resilience conditions, which favor the second order effects (indirect impact) when a seismic hazard event strikes an urban center (Carreño et al., 2007a).

In the holistic evaluation of risk using indices, risk results are achieved aggravating the physical risk by means of the contextual conditions, such as the socioeconomic fragility and the lack of resilience. Input data about these conditions at urban level are necessary to apply the method. This approach contributes to the effectiveness of risk management, inviting to the action through the identification of weaknesses of the urban center (Carreño et al., 2007a).

**TABLE 2.2** Obtained Results for Physical Exposure

| | Physical Exposure | |
|---|---|---|
| Exposed value | € ×$10^6$ | 31,522.80 |
| Average annual loss | € ×$10^6$ | 72.14 |
| | ‰ | 2.29‰ |
| **PML** | | |
| Return period | Loss | |
| Years | € ×$10^6$ | % |
| 50 | 729.35 | 2.31% |
| 100 | 1770.16 | 5.62% |
| 250 | 3699.35 | 11.74% |
| 500 | 5172.26 | 16.41% |
| 1000 | 6510.67 | 20.65% |
| 1500 | 7021.14 | 22.27% |

**TABLE 2.3** Obtained Results for Dead People

| | Dead People | |
|---|---|---|
| Exposed value | Inhab | 1,639,880.00 |
| Average annual loss | Inhab | 28.27 |
| | ‰ | 0.017‰ |
| **PML** | | |
| Return period | Loss | |
| Years | Inhab | % |
| 50 | 101.41 | 0.01% |
| 100 | 654.30 | 0.04% |
| 250 | 2069.97 | 0.13% |
| 500 | 3380.29 | 0.21% |
| 1000 | 4898.39 | 0.30% |
| 1500 | 5799.44 | 0.35% |

**TABLE 2.4** Obtained Results for Injured People

| Injured People | | |
|---|---|---|
| Exposed value | Inhab | 1,639,880.00 |
| Average annual loss | Inhab | 113.55 |
| | ‰ | 0.07‰ |
| **PML** | | |
| Return period | Loss | |
| Years | Inhab | % |
| 50 | 756.92 | 0.05% |
| 100 | 3420.18 | 0.21% |
| 250 | 9028.50 | 0.55% |
| 500 | 12,590.98 | 0.77% |
| 1000 | 15,803.45 | 0.96% |
| 1500 | 16,903.45 | 1.03% |

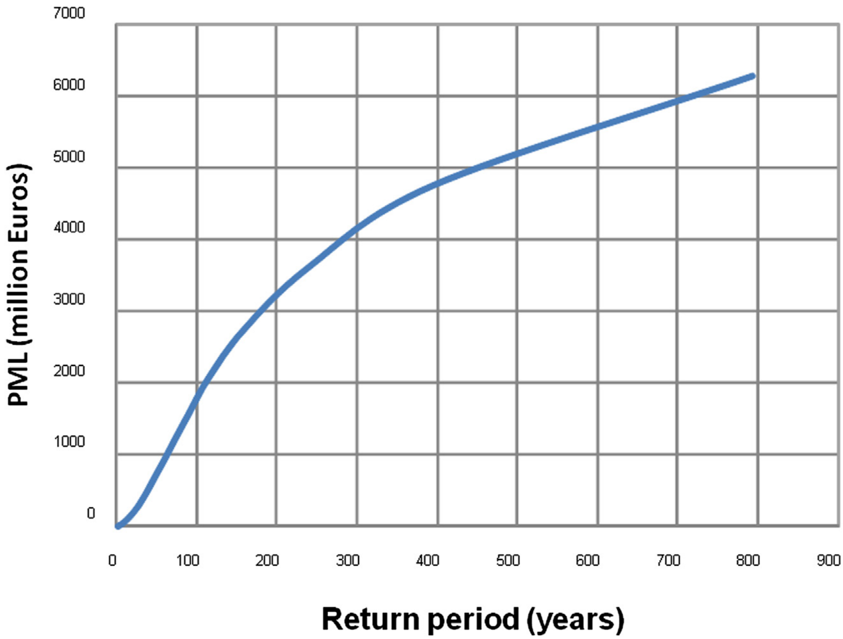



**FIGURE 2.7** PML curve for Barcelona.

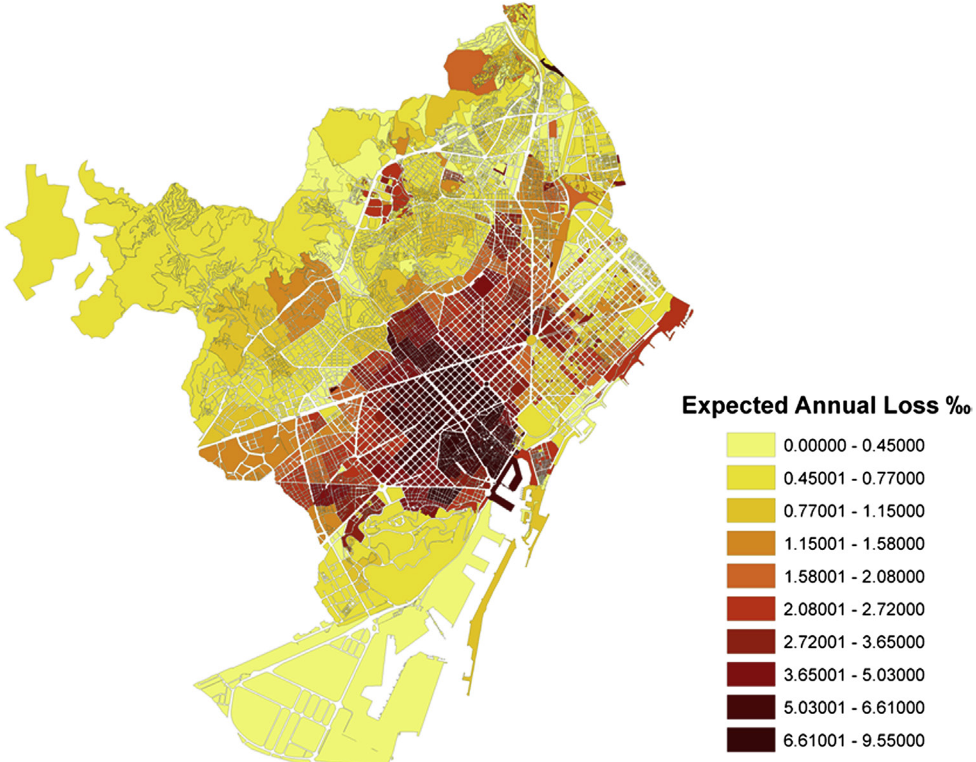



**FIGURE 2.8** Expected annual loss for the AEBs of Barcelona.

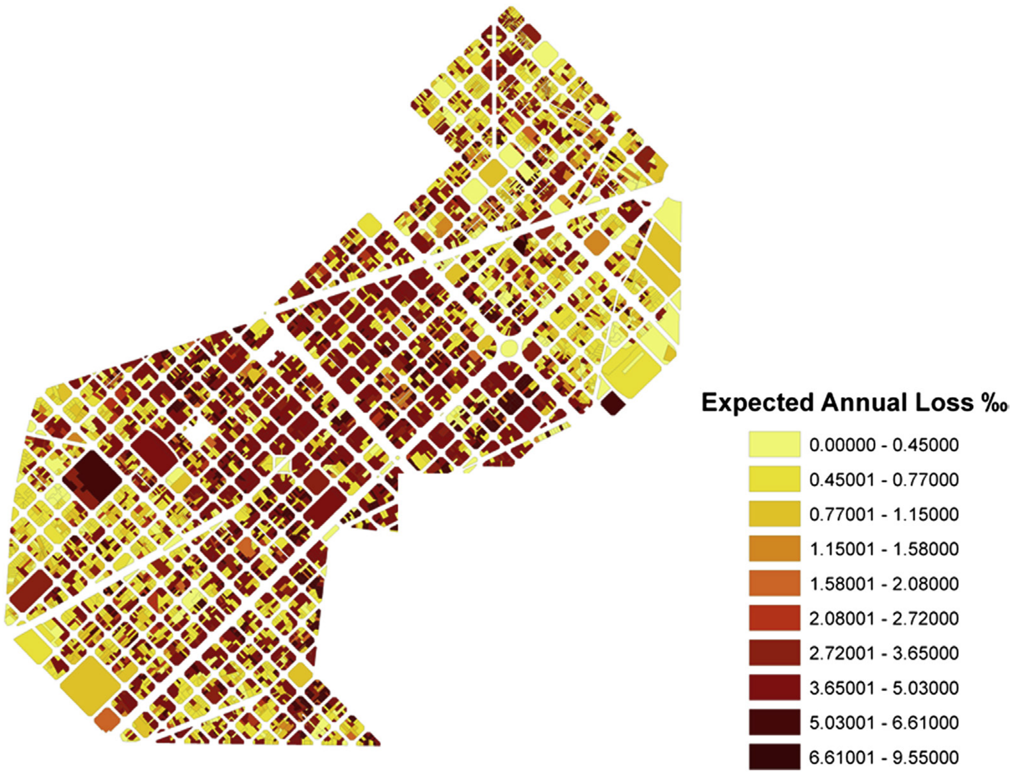



**FIGURE 2.9** Expected annual loss for each building in the Eixample District of Barcelona.

The socioeconomic 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:

$$R_T = R_F\,(1 + F) \tag{2.1}$$

equation 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 aggravating coefficient (Carreño et al., 2007a). This coefficient depends on the weighted sum of a set of aggravating factors related to the socioeconomic fragility, $F_{FSi}$, and the lack of resilience of the exposed context, $F_{FRj}$

$$F = \sum_{i=1}^{m} w_{FSi} F_{FSi} + \sum_{j=1}^{m} w_{FRj} F_{FRj} \tag{2.2}$$

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, which are discussed in the following.

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. Figure 2.10 shows a model for the transformation functions used by the methodology in order to calculate the risk and aggravating factors. They are membership functions for high level of risk and high aggravating level for each. In Figure 2.10, the $x$-axis values are of the descriptors while the value of the factor (physical risk or aggravation) is in the $y$-axis, taking values between 0 and 1, were 0 is the non-membership and 1 is the total membership. The limit values, $X_{\min}$ and $X_{\max}$, are defined taking into account the expert opinions and information about past disasters. In the case of the descriptors of lack of resilience, the function has the inverse shape; the higher value of the indicator gives lower value of aggravation. The weights $w_{FSi}$ and $w_{FRj}$ represent the relative importance of each factor and are calculated by means of the Analytic Hierarchy Process (AHP) on the basis of local expert opinions. The AHP is used to derive ratio scales from both discrete and continuous paired comparisons (Saaty, 1991; Carreño et al., 2007; Carreño, 2006). These comparisons are performed by local experts and the researcher team.

The physical risk, $R_F$, is evaluated in the same way, by using the following equation:

$$R_F = \sum_{i=1}^{p} w_{RFi} F_{RFi} \tag{2.3}$$

Figure 2.11 shows the process of calculation of the total risk index for the units of analysis, which could be districts, municipalities, communes, or

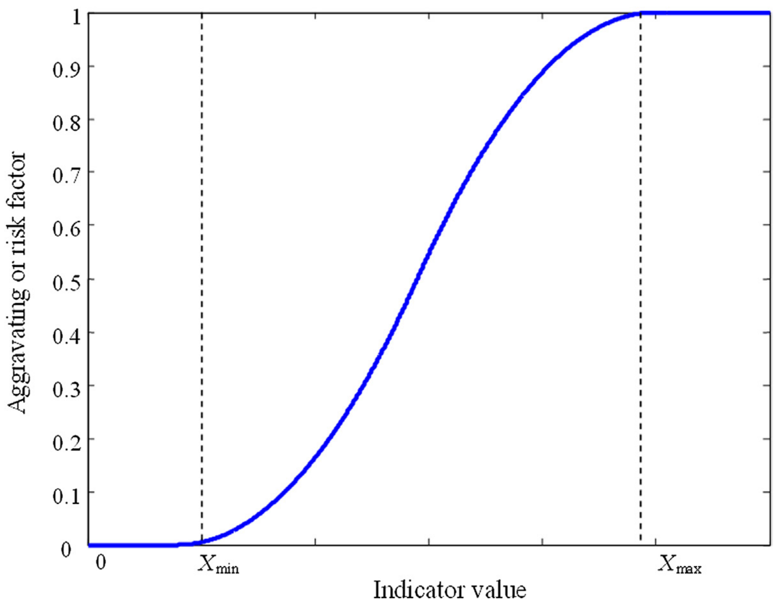



**FIGURE 2.10** Model of the transformation functions.

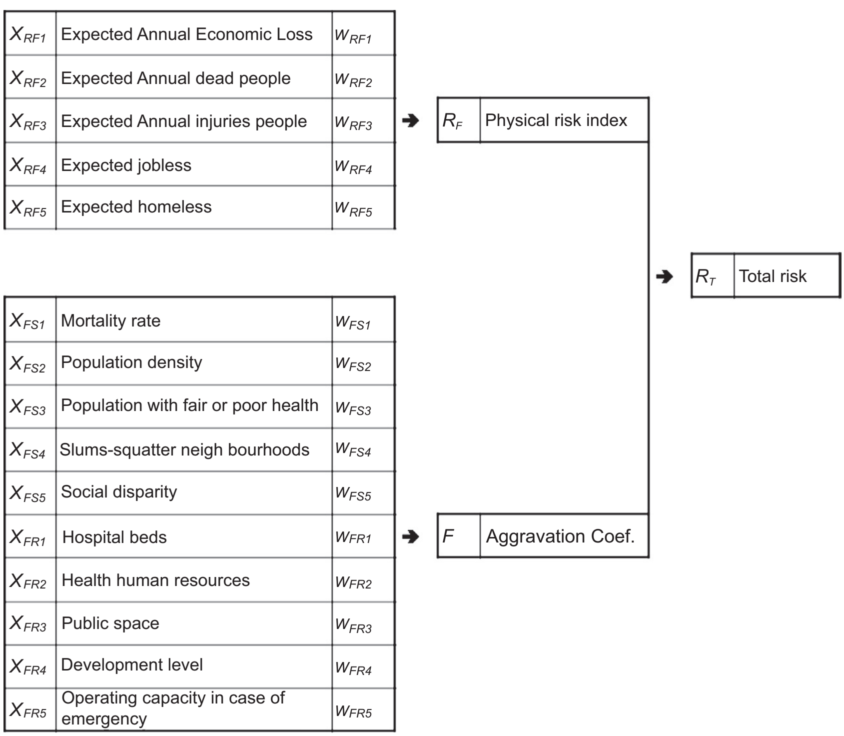



**FIGURE 2.11** Descriptors of the physical risk, social fragility, and lack of resilience and their weights.

localities, starting from the descriptors of physical risk, $X_{RFi}$, and the descriptors of the aggravating coefficient $F$, that is, $X_{FSi}$ and $X_{RFi}$, using the weights $w_{RFi}$, $w_{FSi}$, and $w_{FRi}$ of each descriptor.

This case study is a focus in the holistic evaluation of the seismic risk. Figure 2.11 shows also the descriptors used to describe the physical risk, the social fragility, and the lack of resilience for the case study of Barcelona. These descriptors were chosen as the most significant for each category, and according to available information of the city. The descriptors of physical risk correspond to the obtained results of the probabilistic evaluation of seismic risk of the previous section of this chapter. The descriptors of social fragility and lack of resilience correspond to available information of the city.

Also, the robustness of this methodology has been studied assessing the uncertainty of values and sensitivity to change of values, weights, and transformation functions (Marulanda et al., 2009; Carreño et al., 2009). The methodology is not excessively sensitive to slight variations in the input data and to small changes in the modeling parameters, such as weights and transformation functions. The results do not show important or extreme changes. If the range of variation of data and parameters is reasonable, as it is in the case of seismic risk, the results of the model will be stable and reliable. Detailed information about this evaluation method can be founded in references (Carreño et al., 2007a; Carreño, 2006; Barbat et al., 2011).

The holistic evaluation of risk has been done by following the exposed methodology. Figure 2.12 shows the obtained results of the physical risk index, $R_F$, for the AEB's of Barcelona; Figure 2.13 shows the ranking of the average values for the districts of the city. These results give the highest values of physical risk in areas of the districts of Ciutat Vella and Eixample; these areas correspond to the older areas in the city. The smaller values are in areas of the Nou Barris District and Horta-Guinardo districts.

The results of the aggravating coefficient are shown in Figure 2.14 for each district of the city; Figure 2.15 shows the ranking of these results. The district of Ciutat Vella has the worst aggravating situation according to the characteristics of social fragility and lack of resilience, the best situation is for the Sarria-Sant Gervasi and Les Corts districts.

Figure 2.16 shows the results of the total risk index, $R_T$, for the AEB's of Barcelona. Figure 2.17 shows a detail of the results for the AEB's in the Eixample district; and Figure 2.18 shows the ranking of the average values of $R_T$ for the district of Barcelona.

## 2.6 EVALUATION OF THE RISK MANAGEMENT PERFORMANCE

For management purposes, the risk assessment should be to improve the decision-making process in order to contribute to the effectiveness of risk management, calling for action and identifying the weaknesses of the exposed elements and their evolution over time (Carreño et al., 2007b).

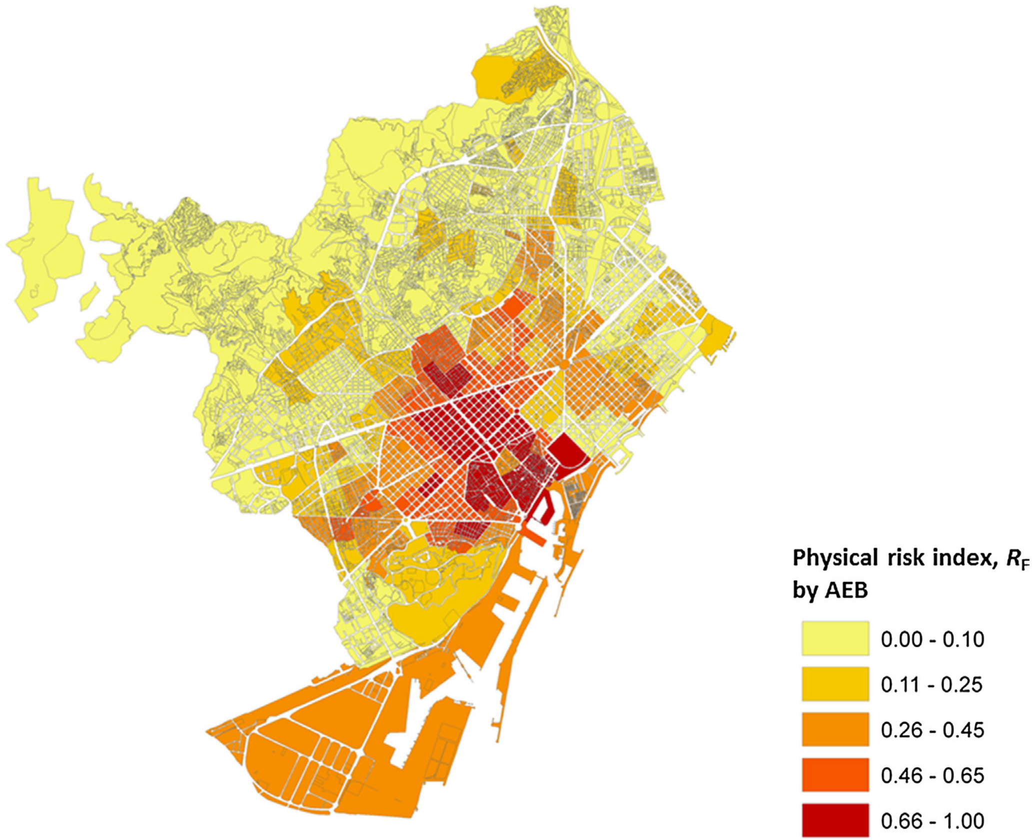



**FIGURE 2.12** Physical risk index.

The evaluation of the risk management performance has been performed by using the methodology proposed by IDEA (2005), Carreño (2006) and Carreño et al. (2007b). This methodology calculates the Risk Management Index, RMI, which brings together a group of indicators that measure risk management performance and effectiveness. These indicators reflect the organizational development capacity and institutional actions taken to reduce vulnerability and losses in a given area, to prepare for crisis, and to recover efficiently from disasters; they are evaluated on the basis of the local expert opinions. This index is designed to assess risk management performance. It provides a quantitative measure of management based on predefined qualitative targets or benchmarks that risk management efforts should aim to achieve.

The RMI was designed to assess risk management performance and, by this way, its effectiveness. It provides a quantitative measure of management based on predefined qualitative targets or benchmarks that risk management efforts should aim to achieve. The design of the RMI involved establishing a scale of achievement levels (Davis, 2003; Masure, 2003) or determining the distance between current conditions and an objective threshold or conditions in a reference country (Munda, 2003). The RMI was constructed by quantifying four public policies, each of which having six indicators. Risk identification index, $RMI_{RI}$, is a measure of individual perceptions, of how those perceptions are understood by society as a whole, and the objective assessment of risk. Risk reduction index, $RMI_{RR}$, involves prevention and mitigation measures. Disaster management index, $RMI_{DM}$, involves measures of response and recovery, and governance and financial protection, $RMI_{FP}$, measures the degree of institutionalization and risk transfer. The four public policies and their indicators were defined after an agreement with several stakeholders and evaluators. Any country or city could redefine them according to own specificities, whereas the parameters are maintained the same in the distinct evaluations over time, in order to make a consistent follow-up of the risk management. The RMI is defined as the average of the four composite indicators

$$RMI = (RMI_{RI} + RMI_{RR} + RMI_{DM} + RMI_{FP})/4 \quad (2.4)$$

Six indicators are proposed for each public policy. Together, these serve to characterize the risk management performance of a country, region, or city. Using a larger number of indicators could be redundant and unnecessary and could make the weighting of each indicator difficult. Following the performance evaluation of risk management method proposed by Carreño et al. (2007a), the valuation of each indicator is based on five performance levels (low, incipient, significant, outstanding, and optimal) that correspond to a range from 1 (low) to 5 (optimal). Examples of these performance levels can be seen as follows for the

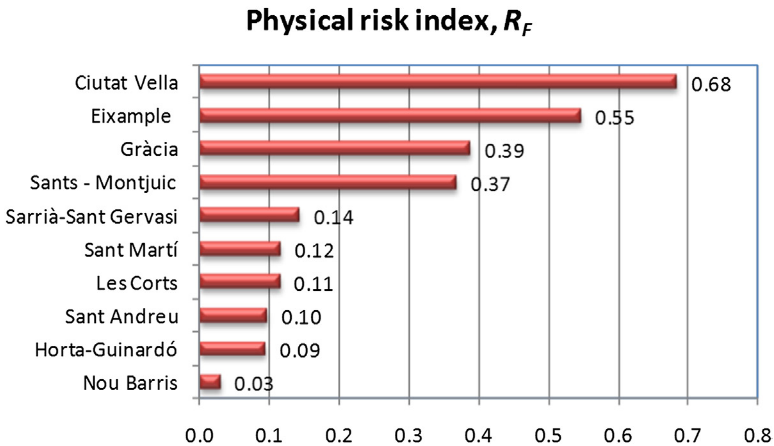



**FIGURE 2.13** Ranking of the average physical risk index for the districts of Barcelona.

case of "Public information and community participation" and "Risk consideration in land use and urban planning".

### 2.6.1 RI5: Public Information and Community Participation

1. Sporadic information on risk management in normal conditions and more frequently when disasters occur.
2. Press, radio, and television coverage oriented toward preparedness in case of emergency: production of illustrative materials on dangerous phenomena.
3. Frequent opinion programs on risk management issues at the national and local levels: guidelines for vulnerability reduction; and work with communities and NGOs.
4. Generalized diffusion and progressive consciousness; conformation of some social networks for civil protection and NGOs that explicitly promote local risk management issues and practice.
5. Wide scale participation and support from the private sector for diffusion activities. Consolidation of social networks and notable participation of professionals and NGOs at all levels.

### 2.6.2 RR1: Risk Consideration in Land Use and Urban Planning

1. Consideration of some means for identifying risk, and environmental protection in physical planning.
2. Promulgation of national legislation and some local regulations that consider some hazards as a factor in territorial organization and development planning.

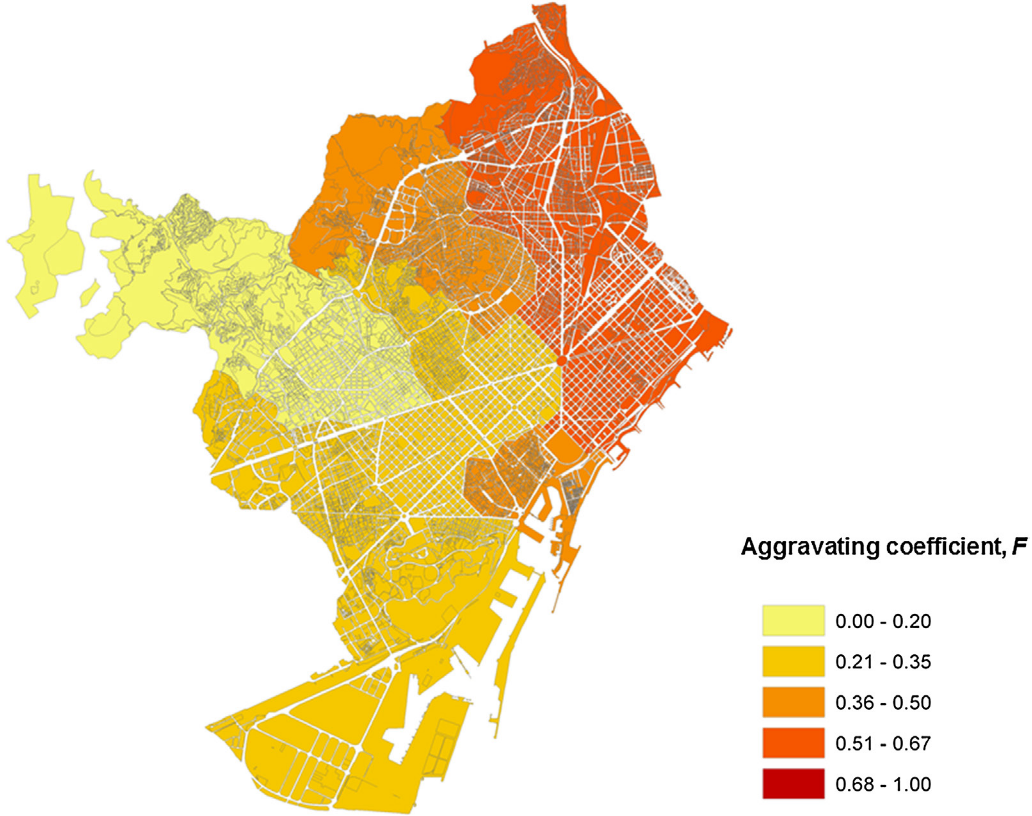



**FIGURE 2.14** Aggravating coefficient for the Barcelona districts.

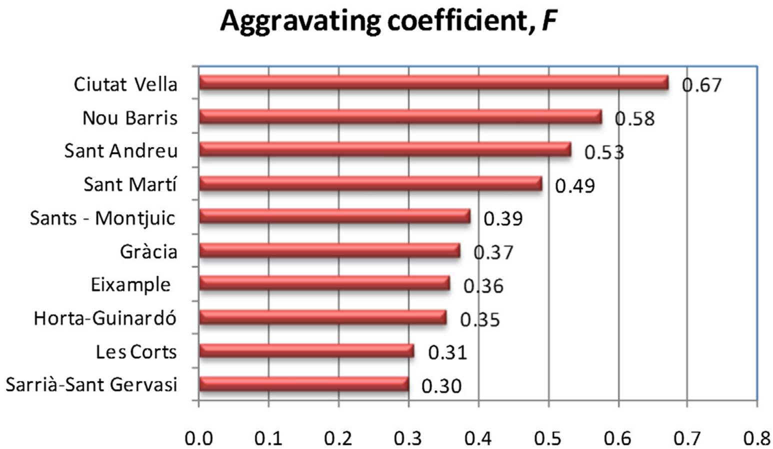



**FIGURE 2.15** Ranking of the aggravating coefficient of the districts of Barcelona.

3. Progressive formulation of land use regulations in various cities that take into account hazards and risks; obligatory de-sign and construction norms based on microzonations.
4. Wide ranging formulation and updating of territorial organization plans with a preventive approach in the majority of municipalities. Use of microzonations with security ends. Risk management incorporation into sectorial plans.
5. Approval and control of implementation of territorial organization and development plans that include risk as a major factor and the respective urban security regulations.

Computationally, these performance levels are represented by using the fuzzy sets theory. This methodological approach permits the use of each reference level simultaneously as a performance target and allows for comparison and identification of results or achievements. Government efforts at formulating, implementing, and evaluating policies should bear these performance targets in mind. Figure 2.19 shows the indicator components of each one of the public policies evaluated by the RMI.

In the case of Barcelona, the indicators have been evaluated by local experts from different disciplines; the obtained results presented as follows are calculated taking the average of the evaluations done. Table 2.5 shows the qualifications for the risk identification indicators and their correspondent weights.

As an example, the development level of the indicator RI2 *(Hazard monitoring and forecasting)* in 2010 was qualified as 4 (*outstanding*). The *Servei Meteorològic de Catalunya* (http://www.meteo.cat/servmet/smr/index.html), for threats of meteorological origin, has a set of equipment for monitoring which includes a network of meteorological observers (XOM), a network of automatic

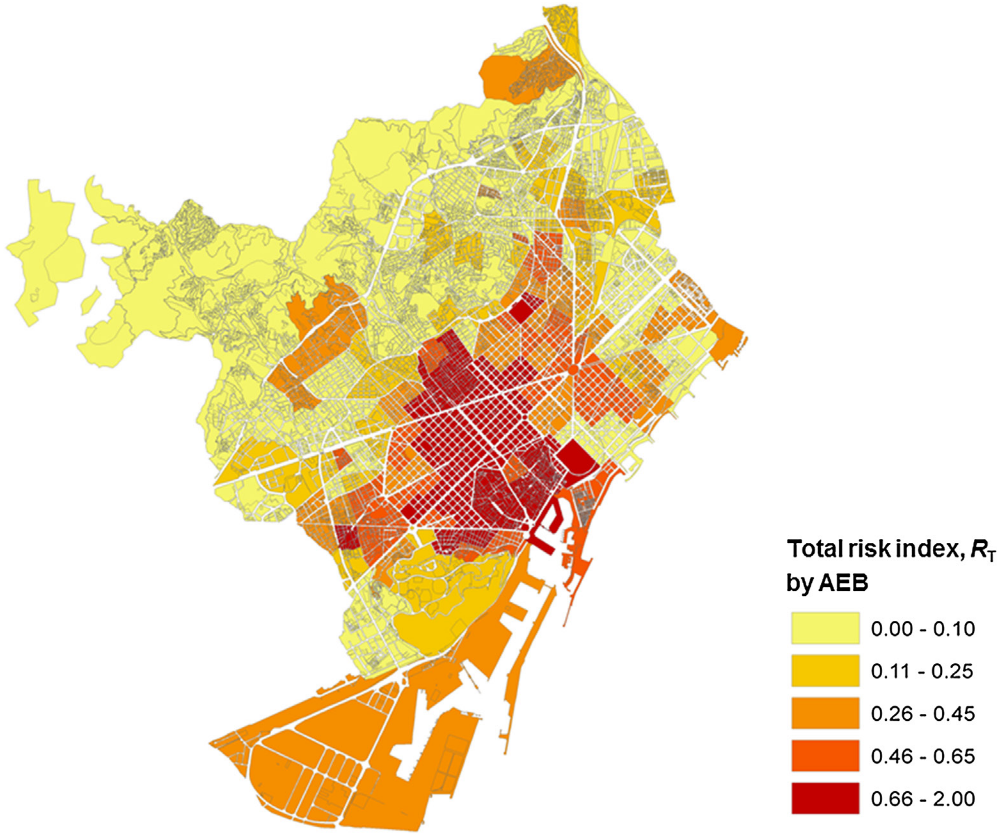



**FIGURE 2.16** Total risk index for Barcelona.

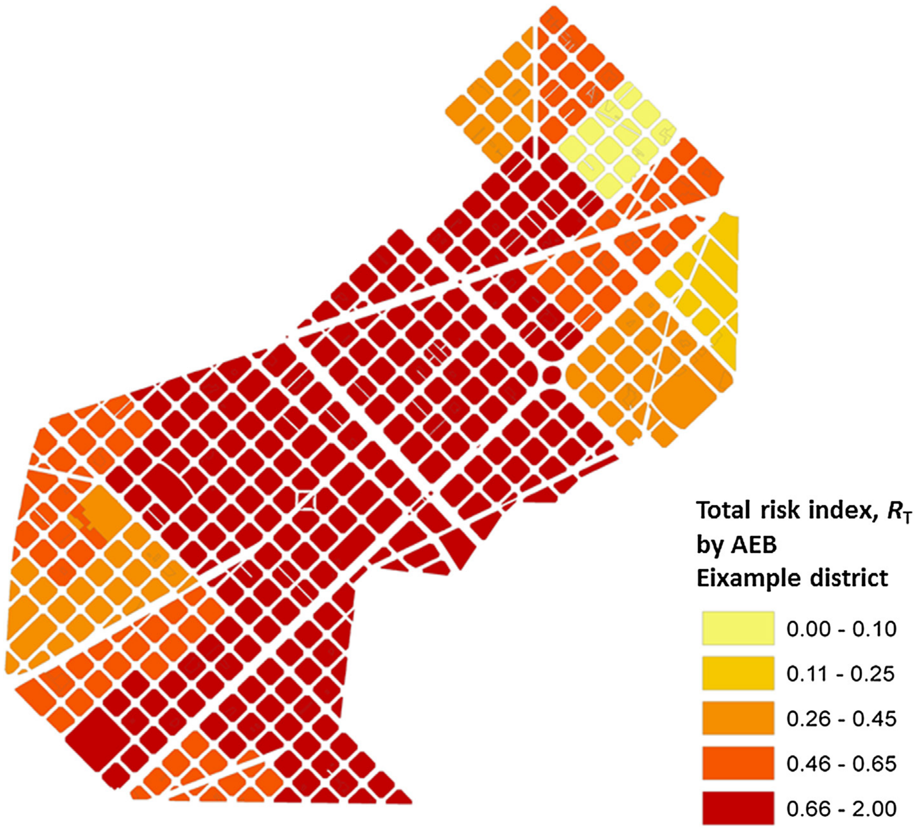



**FIGURE 2.17** Detail of the total risk for the Eixample district.

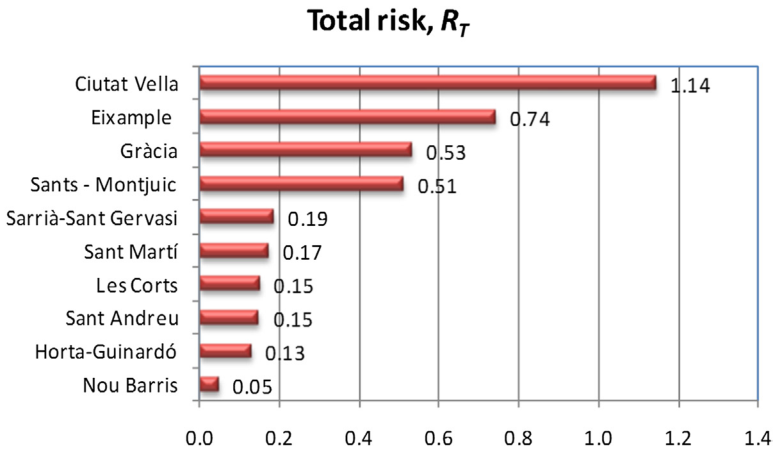



**FIGURE 2.18** Ranking of the average total risk index for the districts of Barcelona.

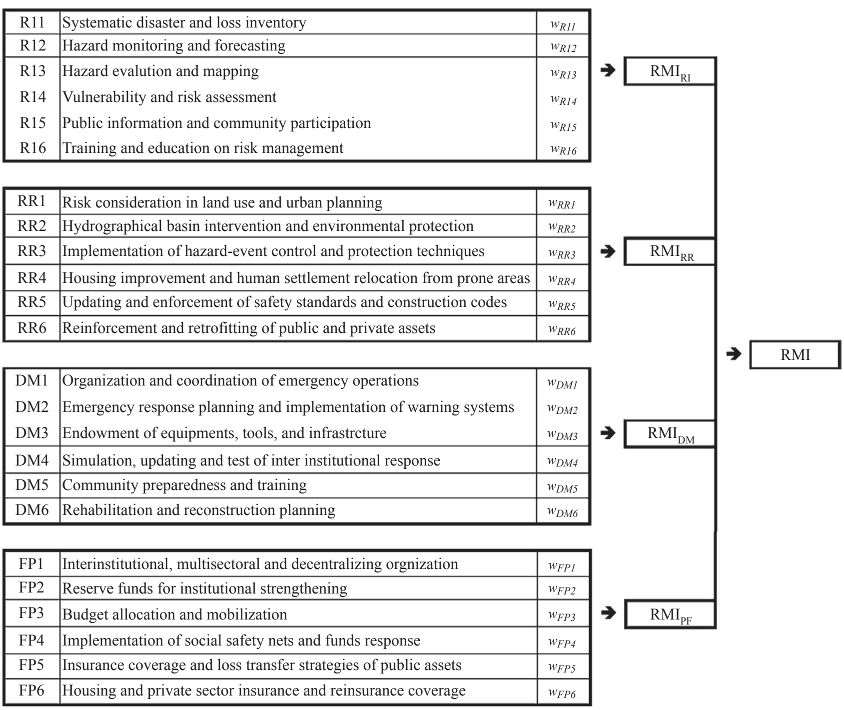



**FIGURE 2.19** RMI and its component indicators (IDEA, 2005).

**TABLE 2.5 Qualifications for the Indicators of Risk Identification (RI)**

| | RI1 | RI2 | RI3 | RI4 | RI5 | RI6 |
|---|---|---|---|---|---|---|
| 1990 | 2 | 2 | 2 | 1 | 1 | 1 |
| 1995 | 3 | 3 | 2 | 2 | 1 | 1 |
| 2000 | 3 | 4 | 3 | 3 | 1 | 1 |
| 2005 | 3 | 4 | 3 | 3 | 2 | 1 |
| 2010 | 3 | 4 | 4 | 4 | 2 | 1 |
| Weight | 22 | 18 | 18 | 20 | 12 | 10 |

weather stations (XEMA), a radar network (XRAD), a network of radio exploration and Meteosat satellite receivers. Some of the functions of this institution are:

1. To schedule, to implement and to manage the system of meteorological phenomena monitoring and forecasting, and to make the exploitation and dissemination in Catalonia
2. To forecast, to watch and to monitor the meteorological risk situations, in coordination with the Emergency Center of Catalonia (CECAT) with a view to improving the effectiveness of activities and ensure appropriate communication to users in may be affected by the system of alerts that is determined by regulatory proceedings
3. To permanently provide, when meteorological risk situations have been forecasted, official meteorological advice to the administrations and institutions responsible for civil protection in Catalonia and to collaborate in such cases, if any, with the meteorological authority of the State
4. To promote research activities in the field of meteorology and climatology and encourage the development of products and services in this area
5. To organize training activities and dissemination in the field of meteorology
6. To carry out studies to improve the understanding of climate and weather in Catalonia
7. To advise and to assist the government agencies on matters related to the study of climate and climate change, in coordination with relevant agencies in this area
8. To advise and to assist the competent public authorities, and to collaborate with them in monitoring and prediction of phenomena and air pollution episodes
9. To analyze and to monitor the characteristics of column ozone in Catalonia in relation to the evolution of stratospheric ozone, and inform the population
10. To study and to analyze climate change in Catalonia and to participate and to collaborate in research on this matter to carry out various groups in Catalonia

With regard to the hazards of seismic and geological origin, the Institut Geológic de Catalunya, IGC (www.igc.cat), maintains a regional seismic network with the aim to monitor the seismicity in Catalonia and nearby areas (Eastern Pyrenees and the Mediterranean Sea). The network is composed of analog stations, as well as digital stations. IGC has a network of accelerometers, most of them with continues transmission in real time.

Tables 2.6–2.8 show the qualification for the indicators of risk reduction, disaster management and financial protection and their correspondent weights. Table 2.9 shows the obtained results for Barcelona.

Figures 2.20 and 2.21 show the obtained results for the RMI and its components for the studied years.

## 2.7 CONCLUSIONS

This evaluation study perfectly fits with the conceptual framework presented in the Chapter 2 of this book. This evaluation includes several elements involved in the conceptual framework such as: seismic hazard, exposure, susceptibility and fragility for physical, social, economical and institutional issues, lack of resilience, risk, risk governance and risk management.

This study develops a risk evaluation with 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. 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.

This 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.

**TABLE 2.6 Qualifications for the Indicators of Risk Reduction (RR)**

| | RR1 | RR2 | RR3 | RR4 | RR5 | RR6 |
|---|---|---|---|---|---|---|
| 1990 | 1 | 1 | 2 | 1 | 2 | 1 |
| 1995 | 2 | 2 | 2 | 2 | 3 | 1 |
| 2000 | 2 | 3 | 3 | 3 | 3 | 1 |
| 2005 | 3 | 3 | 4 | 3 | 3 | 1 |
| 2010 | 3 | 3 | 4 | 3 | 4 | 2 |
| Weight | 16 | 14 | 22 | 15 | 17 | 16 |

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.

The holistic evaluation was done with the basis of a probabilistic analysis of the physical seismic risk. Probabilistic techniques are used to calculate the

**TABLE 2.7** Qualifications for the Indicators of Disaster Management (DM)

| | DM1 | DM2 | DM3 | DM4 | DM5 | DM6 |
|---|---|---|---|---|---|---|
| 1990 | 2 | 1 | 1 | 1 | 1 | 1 |
| 1995 | 2 | 1 | 1 | 1 | 1 | 1 |
| 2000 | 3 | 2 | 2 | 1 | 1 | 1 |
| 2005 | 3 | 3 | 2 | 1 | 1 | 1 |
| 2010 | 3 | 3 | 3 | 2 | 1 | 2 |
| Weight | 27 | 20 | 19 | 11 | 11 | 12 |

**TABLE 2.8** Qualifications for the Indicators of Financial Protection (FP)

| | FP1 | FP2 | FP3 | FP4 | FP5 | FP6 |
|---|---|---|---|---|---|---|
| 1990 | 1 | 1 | 1 | 2 | 1 | 1 |
| 1995 | 1 | 1 | 1 | 2 | 1 | 1 |
| 2000 | 1 | 1 | 1 | 2 | 2 | 2 |
| 2005 | 1 | 2 | 1 | 3 | 2 | 2 |
| 2010 | 2 | 3 | 2 | 3 | 2 | 2 |
| Weight | 20.5 | 15.4 | 17.2 | 12.8 | 17.9 | 16.2 |

**TABLE 2.9** Obtained Results for the RMI and Its Components

| | $RMI_{RI}$ | $RMI_{RR}$ | $RMI_{DM}$ | $RMI_{FP}$ | RMI |
|---|---|---|---|---|---|
| 1990 | 12.61 | 13.29 | 13.23 | 10.77 | 12.47 |
| 1995 | 34.2 | 30.83 | 13.23 | 10.77 | 22.26 |
| 2000 | 49.97 | 34.03 | 35.63 | 11.87 | 32.88 |
| 2005 | 47.21 | 50.9 | 35.84 | 28.07 | 40.5 |
| 2010 | 48.07 | 51.24 | 37.65 | 34.83 | 42.95 |

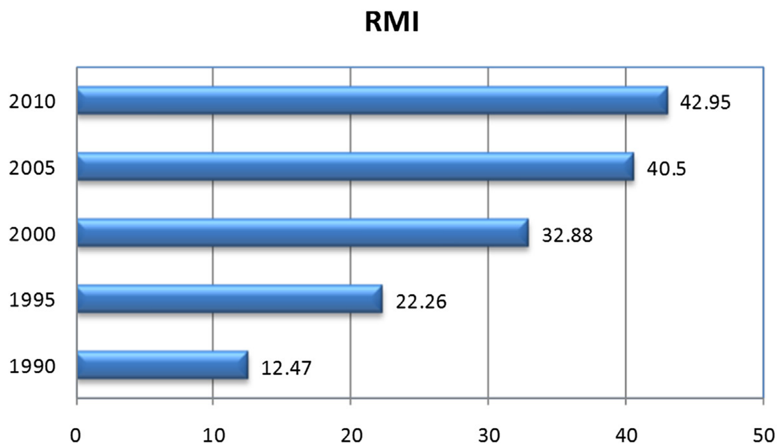



**FIGURE 2.20** Results of the RMI for 1990, 1995, 2000, 2005, and 2010.

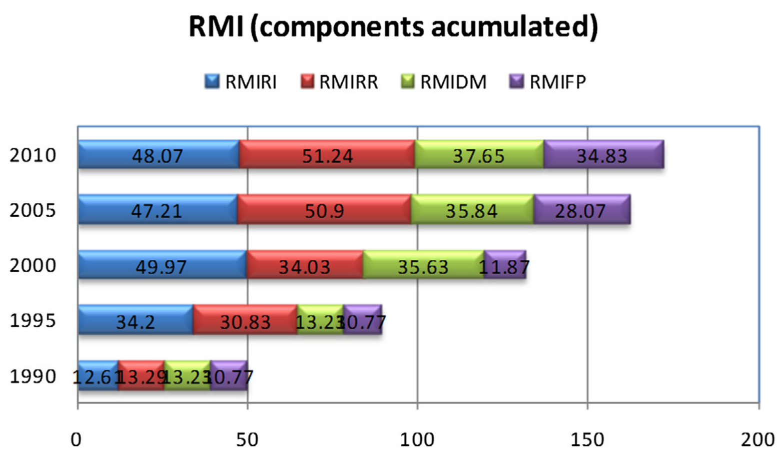



**FIGURE 2.21** Results of the components $RMI_{RI}$, $RMI_{RR}$, $RMI_{DM}$, and $RMI_{FP}$.

Probable Maximum Loss (PML) for different return periods and the Average Annual Loss (AAL) also known as technical risk premium. The CAPRA platform was used to calculate the mentioned metrics for the city of Barcelona, Spain, to estimate scenarios of damages and losses.

The evaluation of the disaster risk management index, RMI, permits a systematic and quantitative benchmarking of the city during different periods. This index not only enables the depiction of disaster risk management at urban level, allowing the creation of risk management performance benchmarks in order to establish performance targets for improving management effectiveness. The obtained results for Barcelona shows an evolution of the disaster risk management in the last 20 years, but also reveals the pending work to be done in this area.

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