Chapter 8

Disaster Risk Assessment Developing a Perceived Comprehensive Disaster Risk Index: The Cases of Three Chilean Cities

Carmen Paz Castro, Juan Pablo Sarmiento and
Claudio Garuti

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/62994

Abstract

A significant increase in the impacts caused by extreme events, of both natural and anthropogenic origin, has been observed in recent decades at a global scale. Chile is no exception to this dynamic. Hazards of various origins and their interactions with socioeconomic, urban, and demographic changes, combined with governance issues have led to a significant risk increase. An accurate assessment of this risk is a significantly complex problem and a holistic approach is required. To address this issue, a multi-criteria decision model has been designed, using the analytic hierarchy process (AHP), which includes qualitative and quantitative variables. The model can be adapted to different contexts, generating a comparable metrics (commensurable) for different cities. The three cities analyzed in this study (Iquique, Puerto Montt, and Puerto Varas) show different levels of risks as a result of a synergic and dynamic combination of factors related not only with natural and physical conditions but also particularly with the variables related to social vulnerability and resilience capacity.

Keywords: Disaster Risk Assessment, Comprehensive Disaster Risk Index, AHP, Commensurability, Risk Perception

1. Introduction

In Chile, the study of risks generates special interest as it is one of the countries with the highest seismic activity around the world. Furthermore, it is exposed to hydro-meteorological hazards, volcanic activity, and tsunamis, among others. Recently, the interest for research on risk assessment and improvement in managing risk has increased notably after the impacts produced by the February 27, 2010 earthquake followed by tsunami. The disaster which affected great parts of the national territory revealed not only the high exposure of the country to the hazard but also the high vulnerability in its various dimensions. The complexity and relevance of the theme deserve special attention to better understand the factors involved in the risk equation and the ability to face future events in better conditions.

More than a decade ago, Lavell (2003) said that disaster corresponds to the materialization of the pre-existing risks in a society, which involve multiple dimensions. Risks should be identified and evaluated urgently in order to take action, going beyond structural measures aimed at reducing the hazard, addressing aspects related to the reduction of vulnerability and exposure of the population and their assets (Siddayao et al., 2014).

In this sense, new determinants that explain the risk conditions in Chile have been mainly associated with changes in the development model of economic globalization followed in recent decades which have brought immense territorial changes. More recently, the climate change scenario, considered an amplifier of extreme events risk, has generated a need for new mitigation and adaptation strategies geared toward an increase in the resilience of the population living in specific territories.

In this context, the research questions that have been raised in this study relate to the issues described by Wilches Chaux (1993) about how risks arise, grow, and accumulate in a particular context. Later, a comprehensive multi-sectoral approach was introduced to improve disaster planning and build more resilient communities (Folke et al., 2002; Walker et al., 2002 in Henly-Shepard et al., 2015:110). Our research emphasizes the need to examine the interactions of the natural and anthropogenic phenomena which constitute the risk in a study area, and the analysis of the dynamics and trends in the construction of risk.

Our study methods are based on the analysis of data from previous research of the authors, the characteristics of the natural physical system in which the community is located, the perspective of evaluation processes that can become threatening, and the population vulnerability and resilience. Risk assessment, the main objective of this research, was based on the analysis of the three variables: hazard (H), vulnerability, and exposure (E). It was performed by applying multi-models and using the analytic hierarchy process (AHP) method (Saaty, 1980). The results allowed the definition of risk areas hierarchy in the three cities considered: Iquique, Puerto Varas, and Puerto Montt. The outcomes of this study will allow, at a later stage, the proposal of areas for protection and occupancy restriction in the territory.

2. Conceptual framework

Progress on the knowledge about social disaster risk construction has positioned the analysis and assessment of the social dimensions as key processes for understanding the underlying risk factors in a territory. These dimensions account for the heterogeneity of a territory expressed in local peculiarities, social perceptions of risk, conditions of vulnerability, and resilience capabilities of the population. A better understanding of the risk drivers requires the identification of social-ecological feedbacks. This is a very challenging issue because of disconnects between social actions and system feedbacks. Feedback mechanisms can be masked through economic distortions, and they may also be deferred in time and space (Berkes et al., 2006; Adger et al., 2009).

The risk is understood as the possibility of suffering losses due to the impact of adverse events such as earthquakes, tsunamis, landslides, and floods. It is related to both the likelihood that an event of specific characteristics occurs and its potential to cause damage which is associated with social and individual considerations as perception (Yamin et al., 2013).

The study of disaster risks has evolved significantly in recent years, having to adapt to new factors and processes that condition them such as the permanent increase in the population's vulnerability, especially in urban areas. As indicated by Kabisch et al., (2011), the risk is increased by factors such as new demographic trends and regional economic developments, which implies the need to study various territorial realities to define underlying causes of general and particular risks, seeking for a comprehensive understanding of the problem.

Earlier methodologies focused on the detection and mapping of natural hazard areas, and on handling emergencies, topics that continue to be relevant and in which significant progress has been made by the various disciplines involved. In this regard, Martinez (2009) notes that natural phenomena (of geological, geo-morphological, and hydro-climatic origin) represent complex subsystems, and become hazards in the presence of humans. The interactions between hazards and populations are under constant change, generating indeterminable possibilities that are manifested in determined levels of risk.

Currently, the need to incorporate the analysis of social vulnerability and exposure in risk assessment is also recognized, advancing a preventive approach that considers the different dimensions of this problem. This is consistent with Olcina's (2008) view that the risk analysis method has evolved from the detailed study of the natural hazard to the vulnerability assessment that those hazards imply and society's response capacity toward the effects of the phenomena of extraordinary range. Gellert (2012) highlights the role of social sciences that has helped address the problem in a more systemic and holistic manner, where a potentially dangerous natural phenomenon can become a hazard in the presence of vulnerable human groups. Actually, vulnerability is understood as a condition, encompassing characteristics of exposure, susceptibility, and coping capacity, shaped by dynamic historical processes, political economy, and power relations, rather than as a direct outcome of a perturbation or stress (Blaikie et al., 1994; Eakin and Luers, 2006 in Miller et al., 2010).

This factor is directly associated with the conditions of social, economic, and environmental fragility (Cardona, 2001), and with the development conditions (Cuny, 1983). These conditions are also defined as prevalent or inherent vulnerability, that is, the conditions under which a society is found when facing an extreme event, and on them depend in an important manner, the level of impact and their differential expression in a territory (Castro-Correa, 2014). According to Cutter et al., (2008), the potential risk is attenuated or increased by a geographic filter (site characteristics), as well as the social network that faces the event. This social network could have community experience in previous events, which can be seen as its capacity to respond, cope, recover, and adapt to adverse events, abilities which are, at the same time, influenced by economic, demographic, and housing characteristics.

Chardon (2002) describes three main problems referring to the risk in Latin American cities. The first relates to the difficulty of avoiding natural hazards (e.g., the case of earthquakes). Then, there is the scope and expansion mode of the urban phenomenon that normally increases risk and, lastly, the absence of the control of the urbanization process (e.g., land use, zoning, and building regulations).

However, individuals and social groups present vulnerabilities and capacities that increase or decrease resilience. The vulnerability includes the susceptibility of people and their livelihoods to suffer harm when facing a hazard, while resilience refers to the capacity of the same subjects to absorb changes and return to their original state (Mayunga, 2007), their ability to anticipate changes, and learn from the experience (Dovers & Handmer, 1992; Folke, 2006; Matyas & Pelling, 2012).

Recent discussions on the relationship between vulnerability and resilience have concluded that these concepts can no longer be analyzed in opposite ways; their analysis must strengthen areas of convergence and synergy between the two, depending on the complexity constituted by the study of socio-territorial systems (Miller et al., 2010). Resilience is not the opposite of vulnerability; the concepts are functionally interrelated. While vulnerability measures the susceptibility of a family group or community to a disturbance, resilience explores the abilities of families and communities to resist and recover from an impact. At the same time, both concepts have attributes that simultaneously manifest and affect the territory (Paton, 2000; Manyena, 2006).

The assessment of risk factors associated with a disaster allows us to identify interventions to improve territorial planning and contribute to increased security and welfare (Wachinger, G and Renn, O, 2010).

2.1. Assessing complex problems: features and advances in multi-criteria modeling methods

According to Yamin et al., (2013), risk assessment should include surveillance and monitoring of hazardous phenomena, along with studies of maps and models of hazard and exposure, to assess the vulnerability of the exposed components. The authors suggest that the difficulties to find adequate risk measurement models in objective terms has serious consequences, as it limits the decision-making process from the perspective of physical planning and the reduction and transfer of risk.

The incorporation of social values in risk assessment requires methods to measure the differences among entities such as money, environmental quality, health, and happiness. There is a broad agreement on the relevance of social aspects in the construction of risk; however, it is at the level of measurement where the challenge remains, because it is difficult to assess the various dimensions of vulnerability and its multi-faceted and dynamic nature (Birkmann and Fernando, 2008). However, the widespread incorporation and use of social scales and theory of measurement has not been incorporated. To address this problem, Professor Thomas L.

http://dx.doi.org/10.5772/62994

Saaty, Ph.D. in mathematics from Yale University, created a mathematical model called AHP in the late 1970s, an effective way to define measures for such elements and use them in the decision-making processes.

The AHP allows identification of the best alternative according to the needs and resources allocated. It acts as a scientific tool to address issues that are difficult to quantify, but nevertheless require a unit of measurement. AHP allows working with several scenarios at the same time with the ability to prioritize economic, environmental, cultural, and political goals. Moreover, it can be used with simultaneous participation of different groups with several objectives, criteria, and alternatives. Its use helps the working group to reach consensus between the interests of different stakeholders or power groups (Saaty & Peniwati, 2008).

The above ideas have been gradually validating themselves (Whitaker, 2007) and incorporating other application areas including the location of power facilities (Marinoni & Hoppe, 2006), planning of investment portfolios (Vaidya & Kumar, 2006), research technologies under uncertainty, territorial planning (Garuti & Castro, 2011; FAO, 1993), assessment of ***smart cities*** (Lombardi, 2012), local development strategies (Silva, 2003), land use and zoning (Siddayao et al. 2014), diagnostic assistance (Maruthur et al, 2014.), shiftwork prioritization (Garuti & Sandoval, 2006), measurements in weighted environments (Garuti, 2012), and decision-making in complex scenarios (Garuti & Escudey, 2005), among others.

The AHP methodology fits well to address problems where the variables involved are of different nature (economic, political, social, cultural, or environmental) and generally difficult to measure. The AHP methodology corresponds to a metric where there is none, or if there is, is not representative or shared unanimously by the decision makers. In fact, this methodology, is with the highest application in the world, has witnessed the fastest growth among the known multi-criteria methodologies (Wallenius et al., 2008).

The theoretical underpinnings of AHP are: (1) the theory of measurement, (2) the graph theory, (3) the sum of Cesaro, (4) the Perron-Frobenius theorem, (5) the theory of disturbances and equilibrium states. AHP also originates from psychological elements and is of biological character: (6) the processes of stimulus-response, and (7) the human capacity for interpretation and transmission of this information on the intensity and amount of electrical discharges of neurons.

The first five points are associated with the theory required to build a model of dominance intensity measurement, also known as ***order topology***, where processes of type are to be determined. For example, if AdB (A dominates B), CdB, and CdA, what is the preference relation between them? Here, it is worth recalling the Arrow's Impossibility Theorem, which says: "In an arrangement of dominances as the one indicated there can be no possibility of complete order."[1] However, it has been demonstrated that this proposition is incomplete (Saaty, 2001); (Saaty, 2006); (Saaty & Peniwati, 2008); (Garuti, 2012), as it supposed—as implicit hypothesis—that such dominances not be taken as cardinal values. That is to say, it is not

[1] Complete order, refers to respecting the five natural properties of ordering set by Arrow).

possible to construct dominance cardinal intensities among the elements, which corresponds to an incorrect hypothesis, including the social aggregation of preferences.

The pursuit of these dominance intensities is associated with the first five points described. From this theoretical basis comes one of the most remarkable results of this method, and that corresponds to identify the vector itself as a reciprocal positive matrix (vector representing the final equilibrium state of a non-consistent or disturbed preference matrix), directly related to the intensities of preference or dominance. This allows associating a cardinal preferences vector to the preferences or dominance judgments initially issued by all decision makers present. On the other hand, the last two points (6 and 7) mentioned above are related to the law of stimuli perception, discovered by the psychologists Weber and Fechner in the nineteenth century. The basic principle of cognitive psychology, which explains stimuli perception, states: "If a stimulus grows in geometric progression, the perception will evolve in arithmetic progression." The principle delivers results in reason or ratio between stimuli as the basis of a fundamental scale (a logarithmic progression).

Thus, these two points (6 and 7) correspond to the construction of a fundamental scale (absolute ratio scale), representing the capabilities and limitations of human beings, and at the same time, respecting the Weber-Fechner law as a proportional cardinal type, that is, it allows the four arithmetic operations within it. All these scale properties are within Saaty's fundamental scale which ranges from 1 to 9, where the value 1 represents the comparison of two equally important elements (A = B), also called neutral value. The value 9 represents the state when one element is extremely important in comparison with the other (A = 9B). More details about this topic can be found in Saaty's book "Decision Making for Leaders".

The AHP theory and its metrics are very useful for complex problems such as risk assessment, where both quantitative and qualitative diverse variables interact synergistically, that must be synthesized to obtain, as in this case, a certain level of risk. These models also allow the analysis of sensitivity of results that can simulate future scenarios and the trends of risk and its components to evaluate decision alternatives.

In this sense, the **objective** of this paper is to conduct a risk assessment of three Chilean cities that have experienced strong growth in recent decades and which present different economic bases and geographical locations. This approach allows identification of the underlying risk factors that illustrate the process of disaster risk construction in intermediate Chilean cities.

2.2. Working hypothesis

The hypothesis guiding this research emphasizes the importance of the social dimension in shaping risk. Risk increase is mainly related to urban sprawl and the significant weakness in land use planning, which have resulted in an increase in population exposure to natural hazards. At the same time, some risks can be accentuated by the manifestation of climate change and climate variability.

http://dx.doi.org/10.5772/62994

2.3. Study area

The three cities selected as study areas (**Figure 1**) have experienced significant spatial change and relevant urban modifications, processes which are explained by the development of their production bases: (1) Iquique (20°13.00′S–70°10′00′W), capital of the Tarapacá Region, free trade city port zone, with great expansion of tourism in the coastal zone, vulnerable to earthquake and tsunami hazards; (2) Puerto Montt (41°28′00′S–72°56′00′W), capital of Los Lagos Region, port and fishing city; and (3) Puerto Varas (41°19′00″–72°50′00′W) of great tourist expansion and satellite town of Puerto Montt. Both Puerto Montt and Puerto Varas are subject to seismic and volcanic hazards.

The three cities selected are prone to hazards of low frequency but high magnitude, in addition to meteorological hazards characterized by high frequency and low magnitude, especially in the south.

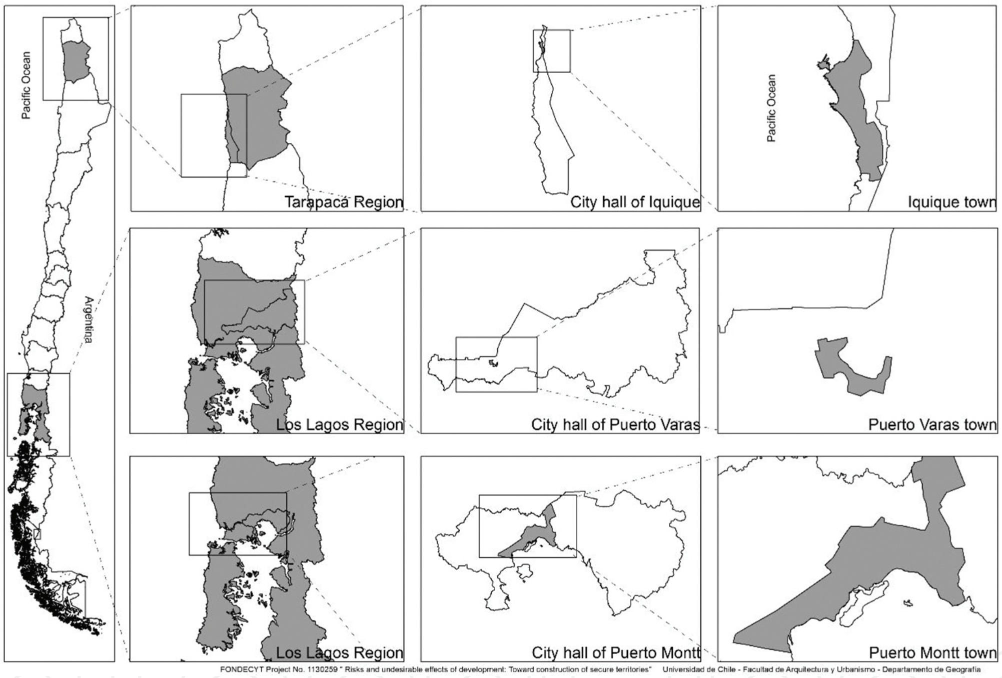


Figure 1. Area of study: Location of Iquique, Puerto Montt, and Puerto Varas cities.

3. Methodology

The methodology for this study is a multi-model approach with four models, each one based in the AHP (Saaty, 1980, 1996), with the goal of assessing disaster risk in a holistic view. This method uses hard data and expert opinion, and provides its own evaluations (based on their knowledge and experience) to obtain the relative weights of the criteria. Through a mathematical process known as hierarchy superposition, the model obtains the value for each alternative using a rating scale (absolute measurement (AM)). The alternatives correspond to the city blocks,[2] and the values correspond to the level of hazard, exposure, and vulnerability.

The process described above allowed us to build a comprehensive index for disaster risk (Disaster Risk Index (DRI)) at block level with four different AHP models (hazards, exposure, prevailing social vulnerability (PSV), and subjective resilience (SR)).

The four models were applied to the three Chilean cities: Iquique (located in the north of Chile), Puerto Montt, and Puerto Varas (both located in the South of Chile). The analysis of the cities was performed at block level, ranking them according to the level of risk, considering the hazards (hazards and exposure), and the social dimension (vulnerability and resilience). This method allowed the study of the functional interactions between the disaster risk components (hazard and social dimension) and its overall impact on the system. The recurring spatial patterns of risk in the study area were evaluated through this multi-model scheme in order to determine the factors that explain the increase of fragility.

The assessment based on the DRI is the result of four evaluation models, namely:

H: Hazard (in negative terms)

E: Exposure (in negative terms)

PSV: Prevailing social vulnerability (in negative terms)

SR: Subjective resilience (in positive terms and acting as a general modulator as an indicator of resilience).

When these four elements are present in a specific order of magnitude, we face a possible disaster.

The outcomes of the four models are synthesized into one to reveal the final value of disaster risk. The values obtained from the four models (which belong to absolute ratio scale) are combined in a way that is mathematically correct. Accordingly, the values of each model have to be commensurate with the values of each of the other models considered.

To accomplish that, the system is divided into two parts or associated functions intrinsically related: H (for hazard) and E (for exposure) on the one hand, and PSV (for PSV) on the other. First, we need to commensurate H with E, by weighting the importance of H and E with the parameters of weight "h" and"e", using "hH+eE". Then, weighted sum of both parts (hazard and exposure from one side with vulnerability from the other) is calculated as: α_1 (hH + eE + HE) + α_2 (PSV). With: α_1: the importance of hazard and exposure, and α_2: the importance of the PSV. Of course, h + e = 1.0 and $\alpha_1 + \alpha_2 = 1.0$. Then, a modulation by (1-SR) over the result of both parts is performed.

It is important to note that SR operates in positive terms, it signifies a value for "capacity of self-protection" or "existing resilience" in the population considered in the study.

Thus, the final expression for DRI is presented as:

[2] A block is an urban space built or intended for building, bounded by streets on all sides.

http://dx.doi.org/10.5772/62994

$$DRI = \left\{\alpha_1\left(hH + eE + H * E\right) + \alpha_2\left(PSV\right)\right\} * \left\{1 - SR\right\} \tag{1}$$

It should be noted that the values of the weights: h, e, α_1, α_2 depend on each situation (of the case study).

The weights (h, e) and (α_1, α_2) were obtained using expert opinion, comparing first the importance of H with E, then the importance of pair (H, E) with PSV. This comparison has to be performed for each location. Also, h, e, α_1, and α_2 represent the values that allow us to add the different absolute scales of measurement involved in EQ1 (hazard and exposure represented by H and E, and social vulnerability represented by PSV).

Note: The theoretical case of "SR" = 1 (100% capacity for self-protection or resilience), then DRI = 0, (no risk of disaster), irrespective of the values of hazard or exposure.

In parallel, theoretical thresholds were calculated for each model and then combined using EQ1, giving an evaluative threshold for a general qualification. The levels to compare the different output values obtained for DRI are: high risk of disaster, medium-high risk, medium-low risk, and low risk of disaster. Each level with a threshold number is built from the local scales of measurement of each model (H, E, PSV, SR) and synthesized using EQ1.

The weighting values of H and E (pair-comparing hazard with exposure) is: h= e= 0.5. This means that hazard and exposure are equally important in the three cities or cases of study.

The weighting values of hazard and exposure with respect to PSV for the three cities are:

City of Iquique: The weighting value for hazard and exposure is 67% and PSV is 33%. This implies that one unit of H and E is twice more important than one unit of PSV.

City of Puerto Montt and city of Puerto Varas: The weighting value for hazard and exposure is 58% and PSV is 42%. This implies that one unit of H and E is 1.38 times more important than one unit of PSV.

A complete explanation of these values (the weights of the models for each city) is given later in "Degree of consistency of decision-makers in comparisons."

3.1. Model criteria

To build the comprehensive DRI, there was a need for adjustments to address the specificities of the hazards present in each city. These adjustments were made in the hazard model, as Iquique (city in the north of Chile) faces substantially different hazards from those found in the cities of Puerto Montt and Puerto Varas (cities located in the south of Chile), as will be explained later in this chapter.

3.2. Criteria and subcriteria weights

To determine the weights of each variable used, an expert enquiry was made with specialists in the area (listed below). This was performed through a pair-comparison matrix taking its principal eigenvector as the representative of their priorities (which correspond to their metric of preferences), accompanied with the consistency index of their comparisons (which correspond to the consistency of that metric).

The four models obtained represent the consensus of these opinions, which were statistically acceptable with a high level of consistency for the four constructed models (exposure, hazard, prevalent social vulnerability, and SR). The consistency, according to this method, indicates that it is a possible measure to be used numerically and its compliance can work numerically with these figures (this rule constitutes a stable measure). The index measures the degree of coherence among the answers of each actor and experts involved in the pair-comparison process.

3.3. Degree of consistency of decision makers' comparisons

Once sorted and entered, the answers in the different models, the level of consistency of answers was checked, grouped by pair-wise comparison matrix, using the formula by Saaty (1980) for consistency:

$$CI = \left[\left(\lambda_{max} - n\right) / \left(n - 1\right)\right] \\ RC = CI / RI < 0.1\left(10\%\right) \tag{2}$$

Where:

CI = consistency index

$\lambda_{\max}$ = highest eigenvalue in comparison matrix (associated with the principal eigenvector)

n = dimension of the comparison matrix

RI = random index of consistency (Saaty, 1980)

RC = ratio of consistency

In cases where the consistency ratio exceeds numeral 0.1 (10%), the response is discarded.

Note: In general, 10% is the value corresponding to the threshold of acceptability of inconsistency. But, if the pair-comparison matrix is a 3 × 3 matrix, the numeral should not exceed 5%.

Overall results for consistency:

Hazard model (H): 0% = 100% consistency

Exposure model (E): 2% = 98% consistency

Subjective resilience model (SR): 3% = 97% consistency

Non-subjective prevalent vulnerability model (PSV): 3% = 97% consistency

Expert judgments provide a high level of confidence to the construction of models and their interpretation (completeness and accuracy in assessing the importance(s)). Using the judgments, arranged in pair-wise comparison matrix for each level of the hierarchy, and the mathematical operator eigenvector, the AHP methodology delivery priorities are outlined in the four models: SR, prevalent social vulnerability, hazard, and exposure.

The variable for SR was obtained through surveys on social perception of a representative sample of the resident population in each of the cities. However, as the surveys do not allow generalization of the results to the entire block, they cannot be represented spatially as the other variables of vulnerability. Thus, our study does not produce SR mapping. The value of SR in our study represents the city as a whole.[3]

SR is of great importance for the development of prevention plans that promote the strengthening of a self-care culture and social participation in risk management in the community, where citizens feel responsible for reducing susceptibility conditions and taking action together with the responsible institutions.

The National Risk Reduction Platform created in Chile by the National Emergency Office of the Ministry of Inner Affairs in May 2013 also targets this objective, recognizing the role of the population in disaster risk management. The Platform is aware that the downward trend observed in the loss of human life in recent extreme events experienced in Chile is mainly due to people's actions that have incorporated the experience of past generations for their protection.

SR measured through perception is a continually changing variable, influenced by factors such as age, knowledge, experience, gender, education level, and cultural factors.

For this reason, SR has been incorporated into the model as a modulator element of the existing level of risk. The values for hazard, exposure and PSV have been weighted by the value calculated for SR.

The H and E modules are considered the most important dimensions in the shaping of the overall risk indicator. In the case of Iquique, 67% of relevance is assigned for H and E due to the geographical location of the city in an area subject to particularly dangerous phenomena such as earthquakes and tsunamis. However, the scale or measurement model of the PSV was assigned 33% importance. This result could be explained by the fact that most of the vulnerable populations are mainly located outside the area of higher risk.

In the case of Puerto Montt and Puerto Varas, even though H and E continue to be the most relevant dimensions, the weighting assigned to them is lower (58%) as tsunami is not a significant hazard in this geographical zone. Vulnerability is assigned 42% weight, an important problem in the cities with many socially fragile zones, usually associated with old informal settlements consolidated within urban areas.

[3] The subjective resilience that measures the social risk perception is a dynamic condition which depends upon many factors. For this reason, and due to the fact that in this case it is a result of a survey applied to a percentage of the population, it was measured through an index that represents the city's population generalized perception in a specific determined time, and which allows to establish relationships based upon the other criteria considered to assess risk. Thus, a sensibility analysis has been generated to assess the prevalence of this dimension over the final result of the DRI.

The exposure variable (E) is weighted by the hazard, as it does not exist if there is no population or its belongings exposed. Thus, its magnitude depends on the relevance of the phenomena as well as the possible social impact it may have, two components of risk that are closely related.

3.4. Specialists consulted

The specialists consulted for the evaluation were:

- Laura Acquaviva, architect, specialist in disaster recovery processes, PNUD consultancy.
- Fabiola Barrenechea, geographer, Risk Management Department, National Emergency. Office (ONEMI).
- Miguel Contreras, specialist in social geography, Assistant Professor of the Geography Department of Universidad de Chile.
- Consuelo Cornejo, psychologist, Civil Protection Office Head of the National Emergency Office (ONEMI).
- Edilia Jaque, specialist in disasters risk reduction issues, Deputy Dean of the Faculty of Architecture, Urbanism and Geography at the Universidad de Concepción.
- Jorge Ortiz Véliz, Associate Professor for the Geography Department at Universidad de Chile, specialist in urban geography.
- Silvia Quiroga, geographer, consultant in risk management issues at OFDA/USAID, professor at Universidad Nacional de Cuyo.
- Jessica Romero, geographer, evacuation programs area, National Emergency Office (ONEMI).

The four models were adapted from the Castro-Correa doctoral study (2014).

4. Risk models

4.1. Risk modeling of natural hazards in the cities of Iquique, Puerto Montt, and Puerto Varas

To comply with the stated objective, four assessment models were run to deliver a synthetic index (DRI) of disaster risk level of each single city block under study.

4.2. Construction of thresholds

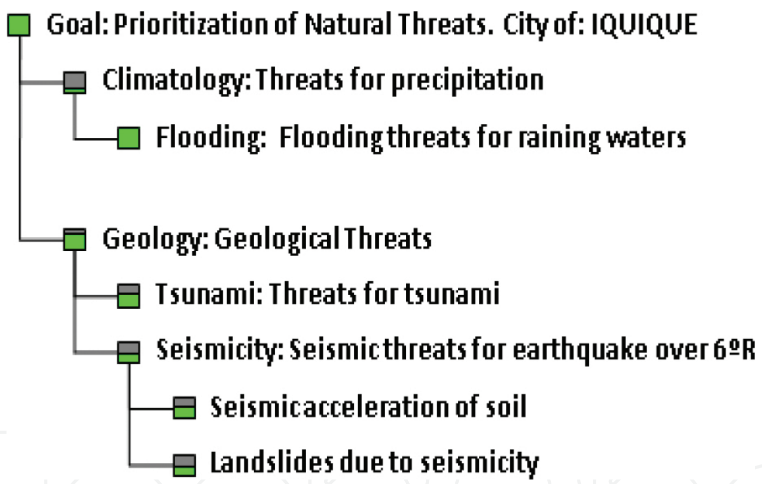
With the configuration of a proportional metric with AM, it was feasible to mathematically construct theoretical thresholds representing the measurement scales of each model. The thresholds were built using the scales of the terminal criteria as information basis, also known as transformation functions, and their corresponding weights. It should be clarified that the assigning of weights to the strategic criteria, as well as to the measurement scales, reflect the national and local realities regarding this subject.

The thresholds help to establish points of reference or classification of each model according to their level of vulnerability to natural hazards. Thus, it can be seen that they do not correspond to ranges of uniform size; on the contrary, they are measures that seek to represent reality in the best possible way.

Next, the four multi-criteria models on the AHP platform (Hazard, Exposure, Social Vulnerability and SR), all in AM mode are presented below. The weighting of the criteria of each model can be seen in brackets to the right of each criterion.

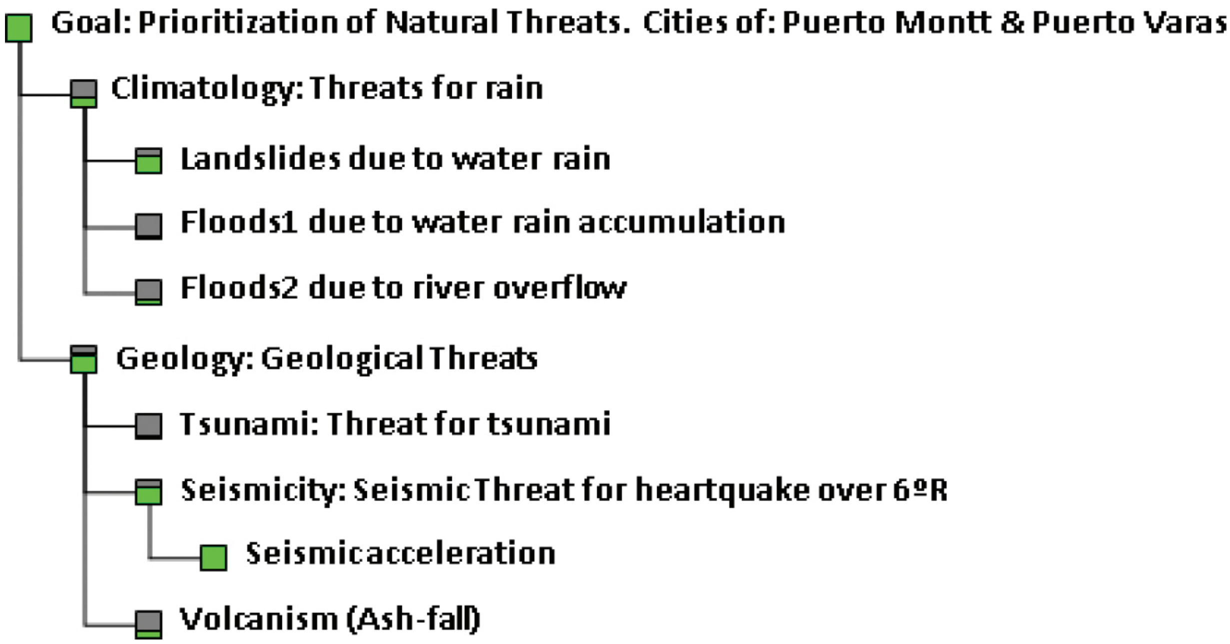
4.3. Hazard models (H)

Two different models were run for the cities located in different geographical locations, as geological positions and morpho-climates influence the existence of certain types of hazards. A model of hazards for Iquique (HI), a city located at a zone corresponding to a coastal desert area, and one for Puerto Montt and Puerto Varas (HP), cities located in the southern rainy and cold region, were defined. Next, the adjustments carried out in each (HI) and (HP) are explained (**Table 1** and **Table 2**).



Climatology	Hazards due to precipitation
Flooding	Flooding hazards due to raining waters
Geology	Geological hazards
Tsunami	Hazards due to tsunami
Seismicity	Sesimic hazards due to earthquakes over six in Richter scale
Seismic acceleration	Soil acceleration
Landslides	Landslides hazards due to seismicity

Table 1. Criteria definition table for the model of hazards in the city of Iquique (HI).



Climatology	Hazards due to precipitation
Floods1	Flooding hazards due to raining waters
Floods2	Flooding hazards due to river overflow
Geology	Geological hazards
Tsunami	Hazards due to Tsunami
Seismicity	Sesimic hazards due to earthquakes over six in magnitude scale
Seismic acceleration	Acceleration of soil
Volcanism	Volcanism hazards due to ash fall

Table 2. Criteria definition table for the model of hazards in the cities of Puerto Montt and Puerto Varas (HP).

4.4. Hazard model for the city of Iquique (HI)

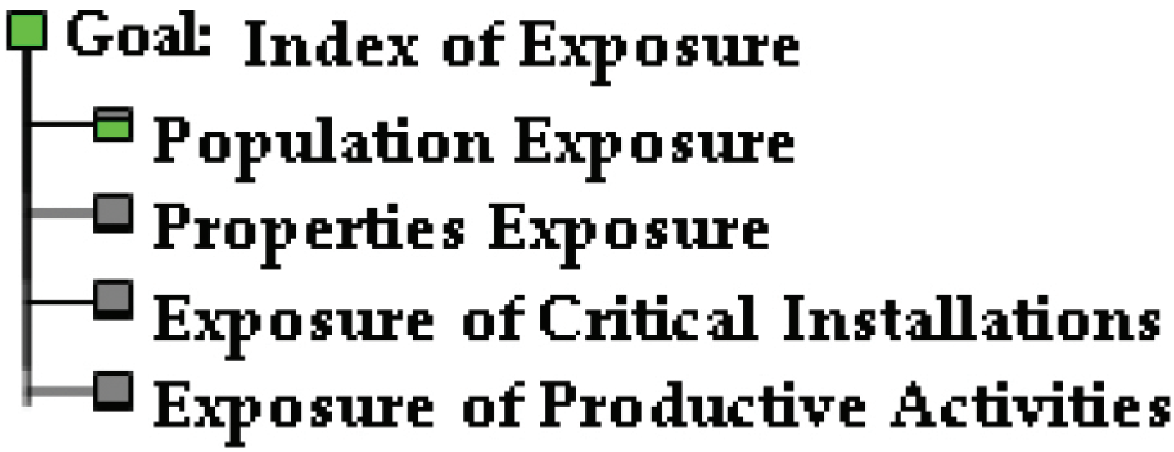
In the model Hazards Iquique (HI), the geological hazards with a weight of 77.8% outweigh the weather hazards (22%) due to the low rainfall experienced in the city. The seriousness of the geological hazards, earthquakes and tsunamis, is the reason for their importance (46.7%) in comparison to all other hazards considered for the city. The model rates the importance of geological hazards at 46.7% in comparison with other hazards, mainly because of the seriousness of earthquakes and tsunamis in Iquique.

4.5. Hazard model for the cities of Puerto Montt and Puerto Varas (HP)

In this case of HP, the geological hazards (67.1%) exceeded the climatic ones (32.9%), but the difference between the two is not as great as in the case of Iquique. The city of Puerto Varas is not located in the coastal zone and Puerto Montt is protected from large tsunamis, so the main geological hazard is the seismic one (44.2%). Another hazard of geological origin, volcanoes, is weighted low (17.6%), as it is only present in the form of ash fall and not lava or lahars (**Table 2**).

4.6. Exposure model for the three cities (E)

The model for E is a fairly simple one and consists of four criteria or variables that allow measuring exposure of people and their livelihoods to the hazards defined in the previous model. The criteria are: Population, Housing, Critical Facilities, and Productive Activities (**Table 3**).

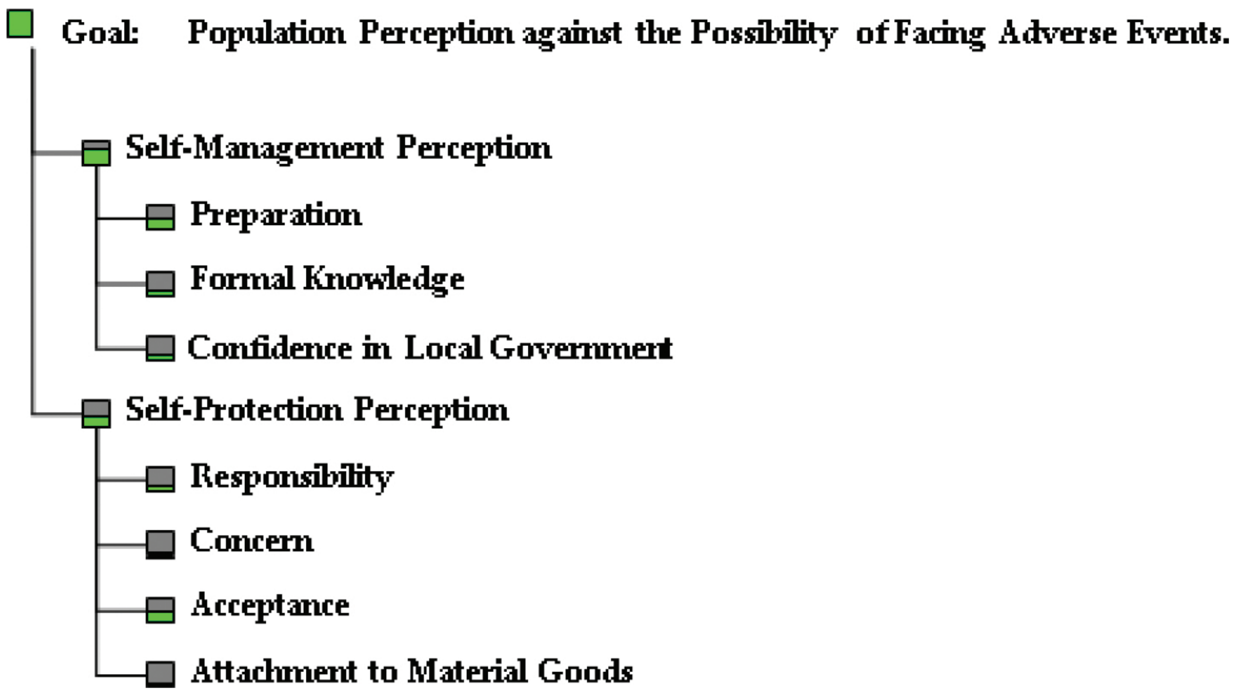


Population exposure	Degree of exposure of people to the natural hazards (the most important exposure)
Properties exposure	Degree of exposure of properties to the natural hazards
Exposure of critical installations	Degree of exposure of electricity, telephone lines, water pipes, and waste waters installations
Exposure of productive activities	Degree of exposure of the most important productive activities in the city

Table 3. Criteria definition table for the model of exposure (E).

4.7. SR model for the three cities (SR)

The next model measures the population's SR. This corresponds to measuring the perception of the population's possibility of facing adverse events, specifically to evaluate their resilience capabilities. As resilience mitigates risk, the model operates in the opposite direction of risk, which explains the use of SR as (1-SR), a risk modulator, in Eq. (1) (**Table 4**).



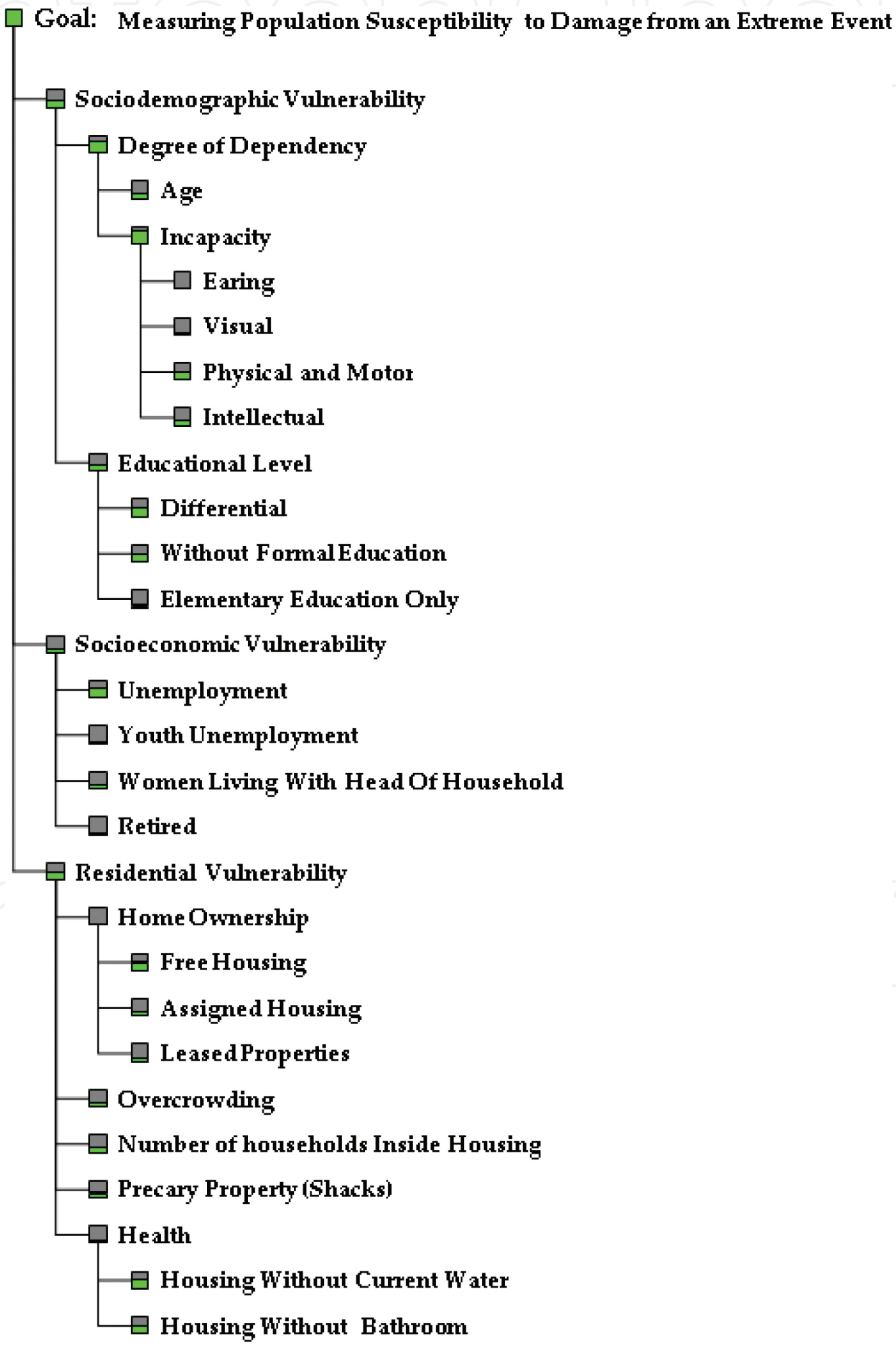
Self-management perception	People's perception about their own preparation, formal knowledge, and confidence in local government to face adverse events
Preparation	Level of preparation of people to face adverse events (perception)
Formal knowledge	Formal knowledge about how to face adverse events
Confidence in local government	Degree of confidence of people in the local authorities
Self-protection perception	People's perception about their own responsibility, concerns, acceptance, and attachment to material goods to face adverse events
Responsibility	Level of responsibility (perception) to face adverse events
Acceptance	Level of acceptance (perception) to face adverse events
Attachment to material goods	Level of attachment to material goods (perception) when facing adverse events

Table 4. Criteria definition table for the model of subjective resilience (SR).

When reviewing the model, it is possible to verify that the two variables or criteria most important to measure the subjective perception of the population are: the level of preparation of the population to face these events (30.2%) and the level of acceptance of the situation (18.1%). Slightly less importance was given to the level of formal knowledge (formal education) (15.1%), which was valued equivalent to the level of confidence that exists for local institutions (15.1%) to face extreme situations.

4.8. Prevalent social vulnerability model for the three cities (PSV)

The model of PSV is the most complex one and is linked to the non-subjective prevailing vulnerability, that is, the vulnerability of the population before the occurrence of an extreme event that responds to the factors identified in the model (**Table 5**).



Socio-demographic vulnerability	Degree of vulnerability due to socio-demographic characteristic of people in the block
Degree of dependency	Measures the degree of dependency in the block
Age	Age of people in the block
Disability	Different types of disability reported: hearing, and visual impairments, physical and intellectual disability
Educational level	Level of formal education (differential, without formal education or elementary only)
Socioeconomic vulnerability	Degree of vulnerability due to socioeconomic characteristics of people in the block, it depends on number of: unemployed people, unemployed youth women acting as head of household, and retired (jubilee) people.
Residential vulnerability	Degree of vulnerability due to the residential precariousness
Home ownership	Vulnerability due to type of ownership: free housing, assigned housing, or leased
Overcrowding	Vulnerability due to overcrowded house
Number of families inside a dwelling	Vulnerability due to more than one family present inside one dwelling
Precarious property	Vulnerability due to precarious level of property (shacks)
Health	Vulnerability due to level of health inside the residence, produced primarily by two issues: housing without current water and housing without bathroom.

Table 5. Criteria definition table for the model of social vulnerability.

The two most important criteria are residential vulnerability (42.3%) and socio-demographic vulnerability (35.9%). On the other hand, the most relevant criteria or measuring indicators within socioeconomic vulnerability is unemployment (12.4%). Within residential vulnerability, it is the substandard housing (12%), the number of families per dwelling (10.3%), and overcrowding (8.2%), whereas in socio-demographic vulnerability, the most relevant criteria include physical-motor disability (9.5%) and intellectual disability (6.2%). These six indicators account for almost 60% of the total weight of the 20 indicators that make this model, demonstrating its importance as factors that explain the PSV.

5. Application of the risk models to the cities of Iquique, Puerto Varas, and Puerto Montt

To apply the metrics of each model on the three cities analyzed, the information of all the criteria or variables considered for each cell[4] or block of the city was analyzed. 1500 cells for

[4] A cell is the territorial unit selected in the study where the four models are applied and for which DRI is calculated.

the city of Puerto Montt, and 3000 cells for all three cities were assessed. Each cell was assessed in absolute measurement at each terminal criterion or model indicator, using a specific cardinal scale (natural) to the terminal criterion or measurement model indicator. This was done systematically for each cell of each model.

Finally, the four models (H, E, PSV, and SR) were integrated using EQ1 and as a result, we obtained the comprehensive DRI of each cell.

It is important to remember that:

- The sum of the different models (each containing different metrics) is possible because the integration formula considers the weighting values: **h**, **e**, α_1 α_2 The weighting values "h" and "e" make the measurement units of hazard and exposure comparable. The weighting values α_1, α_2 make the common measurement unit (H-E) commensurable with unit of measurement of PSV. The final outcome is weighted by (1-SR), which is the complement value of SR. Since SR is a positive element in the disaster risk equation (EQ1), it works as a modulator or "shock absorber" of the overall risk in each cell of the city.
- The level or scale of analysis achieved is feasible because the required information is at the block/cell level, which allows a very detailed disaster risk analysis for each city.

5.1. DRI, city of Iquique

The modeling considered the different variables or risk factors for the city of Iquique and applied the DRI index to the block level. The result of this graphical process (**Figure 2**) shows that medium-low risk conditions is dominant in the city, while low-risk areas, mostly near the civic center, are scarce. These results are consistent with the reality of a city that is, like many Chilean cities, exposed to different hazards like earthquakes, tsunamis, and landslides. Moreover, a distinct level of social vulnerability expressed through factors such as the precariousness in housing, overcrowding, poor education, disability, and unemployment, among others, increases the susceptibility to suffering damages and difficulties in recovering from a disaster event.

The Iquique waterfront shows a medium-high level of risk, mainly due to the significant and growing population exposure to tsunamis in this area. Although a medium-high level implies greater danger, the risk becomes somewhat lower when integrated with the hazard modeling and exposure to the PSV. This is justified because the Iquique waterfront is characterized by low PSV, as it is generally inhabited by people of medium-high and high socioeconomic strata. Their economic capabilities allow them to prepare for emergencies and quickly recover post disasters events as seen after the earthquake in 2014. In addition, this population, with a strong support network, demonstrates independence in decision-making, showing management capacity, and resilience which modulates or dampens the hazard and exposure present in the cells of this zone. These results indicate that the process of integration of the four models is not only interesting but also necessary for proper assessment and later qualification of the degree of disaster risk in a specific area.

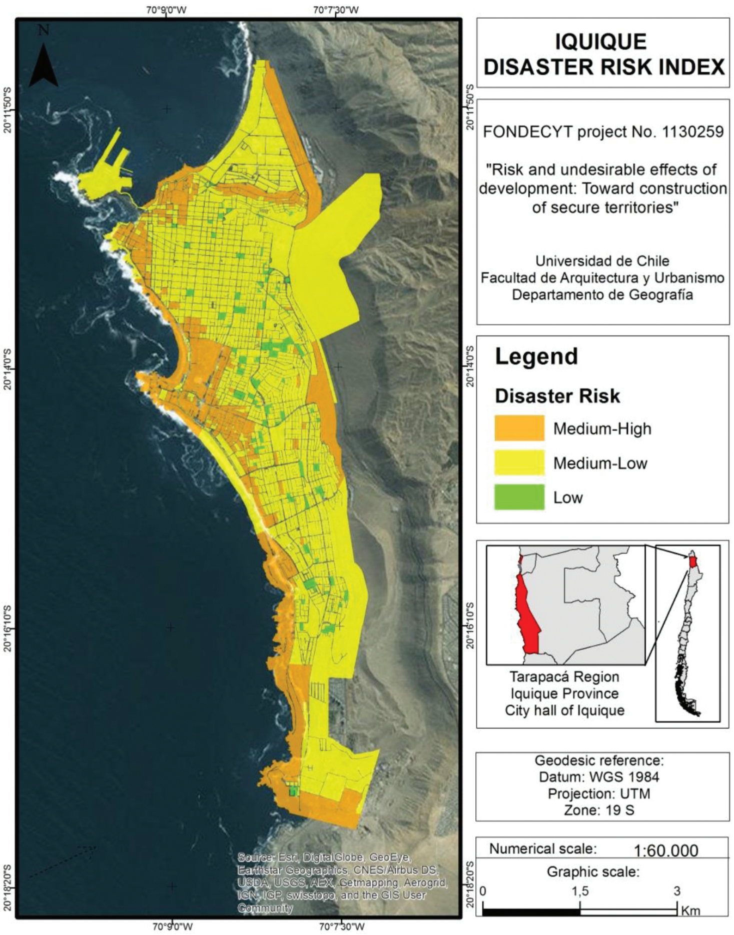


Figure 2. Disaster Risk Index, Iquique City.

The northern coastal area, an industrial region, with a high probability of a tsunami, shows a low-medium risk as it has virtually no residents (E = 0) and thus does not present values of social vulnerability (PSV = 0). However, this result could be questioned as a sizeable number of people work in this area during the day. The model, in the first instance, does not consider this floating working population due to lack of information about them. This could be remedied by performing a sensitivity analysis by incorporating this population and its characteristics, building a scenario where DRI values display the day index situation in the zone's cell.

There are zones with a medium-high risk immediately south of the industrial area with values in the upper limit, that is, a slight deterioration in their condition can move the zones to the category of high or unacceptable risk. This area brings together several negative conditions that maximize each other: the exposure of large populations and critical facilities (health care) to tsunamis, along with vulnerable populations such as a large number of dependent people, people with cognitive disabilities, people with low education level, unemployed people, and a significant number of female as heads of households. This outcome is reflected in the comprehensive risk index at the cell level (as shown in the value of the integrated DRI index).

The classification of cells by risk levels helps the prioritization of risk interventions and resources allocation.

The application of the EQ1 for Iquique is given in **Table 6**.

Alternative	α_1	Hazard (H) (a = 0.5)	Exposure (E) (e = 0.5)	α_2	PSV	SR	DRI(37)
Block 37 (Medium-high)	2/3	0.5243	0.8650	1/3	0.4209	0.2676	**0.6636**
		Medium-High	*High*		*Medium-High*	*Medium-Low*	*Medium-High to High*

Table 6. Applying EQ1 equation to calculate[21] the DRI in block[22] 37 Iquique city.

DRI(37) = [2/3*(0.5*0.5243 + 0.5*0.8650 + 0.5243*0.8650) + 1/3*(.4209)] * [1 - 0.2676] = 0.6636 (Risk medium – high to high).

Notice: Block 37 has a DRI = 0.6636 ≈ 0.6832, is only 2.9% below the limit considered unacceptable (0.6832). Also, the exposure value for this block (0.8650) is far over the specific threshold for exposure (0.6003), this is about 44.1% over the upper limit.

The upper limit (threshold) of DRI calculated for Iquique is 0.6832. Anything above should be considered unacceptable level of risk disaster.

This analysis methodology (working with cardinal numbers) also allows analysis of an average cell or average block, for the city of Iquique. The average cell is representative of the average behavior of the city, as if this were all included in a single cell.

Below is a table with the behavior of the average cell in each model and its final value calculated using Eq. (1) (**Table 7**).

	α1	**Hazard**	**Exposure**	**α2**	**PSV**	**SR**	**DRI**	**Qualification**
Average Cell	2/3	0.1946	0.4563	1/3	0.2299	0.2676	**0.2585**	Medium-low

Table 7. Average block behavior Iquique.

Note: It is important to remember that the values obtained for Iquique DRI have a different rule of measurement than the cities of Puerto Montt and Puerto Varas, (since it has a different Hazard model). Therefore, they are not comparable values. This "non-comparability" also applies for the outcome of the average cell.

5.2. DRI, city of Puerto Varas

The most populated area of Puerto Varas generally presents a low average risk; however, its expansion areas, such as the northwest area of the city, have a (medium-high) risk. The lower-risk area is located in the city center, away from flood or landslide prone areas, and only presents the same risk level as the rest of the city for the hazards of volcanic ash fall and earthquakes. In contrast, some areas near the waterfront in the southern part of the city have very high exposure levels to landslides. The population here, with no formal or only basic education, is highly dependent because of the significant presence of seniors and to a lesser extent, people with hearing impairment.

These factors explain the level of risk in this zone which could be mitigated by infrastructure and territorial planning.

The south of Puerto Varas (an area furthest from the lake at a higher elevation) is associated with high overall risk mainly because of higher social vulnerability along with the high impact, low frequency hazards such as earthquakes and ash fall. The frequently recurring hazards like floods and landslides do not pose significant impacts.

5.3. DRI, Puerto Montt City

The city of Puerto Montt presents a medium-high risk level virtually in its entire urban area (**Figure 4**). Overall, the risk in the city is associated with the escarpments of marine terraces and presence of areas prone to landslides. The landslides have led to the loss of homes, and a high risk for families who inhabit those neighborhoods and have already experienced damage

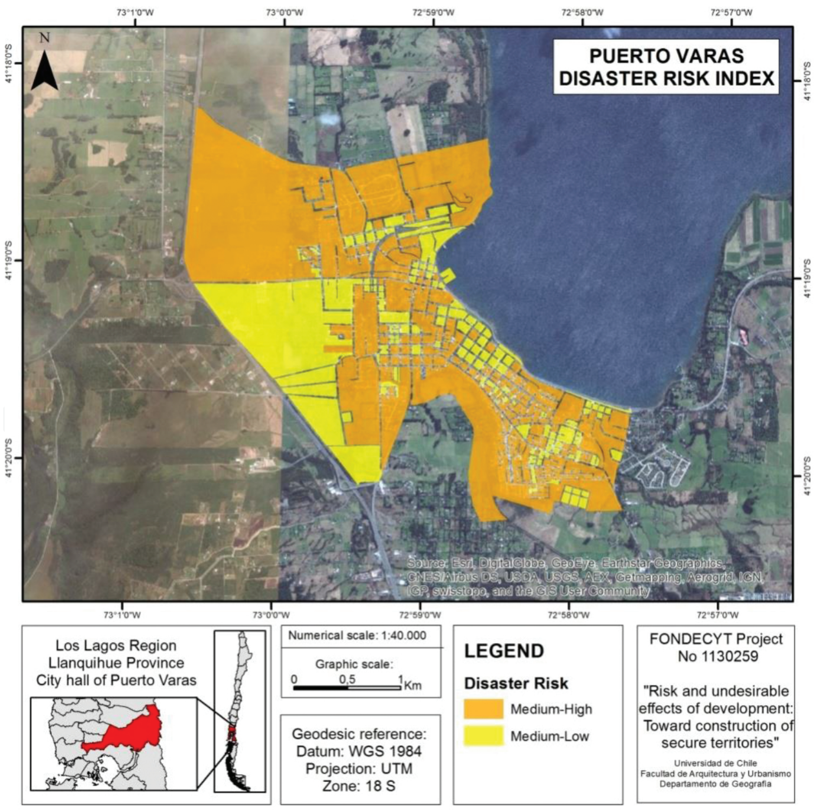


Figure 3. Disaster Risk Index (DRI), Puerto Varas.

http://dx.doi.org/10.5772/62994

and losses in dwellings and livelihoods. The local government is working on regulations to limit the use of areas at risk for residential purposes, and to relocate the existing population, designating this land as environmental protection zones. Another significant hazard is linked to the stream banks that cross through the city and cause flooding during heavy rainfall episodes. These areas are usually occupied by informal settlements characterized by precarious homes and utilities, resulting in medium-high risk levels, very close to unacceptable risks.

The areas of future expansion present a medium-low level of risk, as despite the low exposure of population and infrastructure, these are landslide prone and recurrent floodplain areas which require important investments in mitigation works to assure a sustainable future.

The recent expansion areas situated westward, toward the airport, exhibit the same precarious features mentioned above, and have been urbanized with densely populated plots and very few green areas, normally associated with populations with a high level of social vulnerability. However, there is a potential for risk reduction through improved infrastructure.

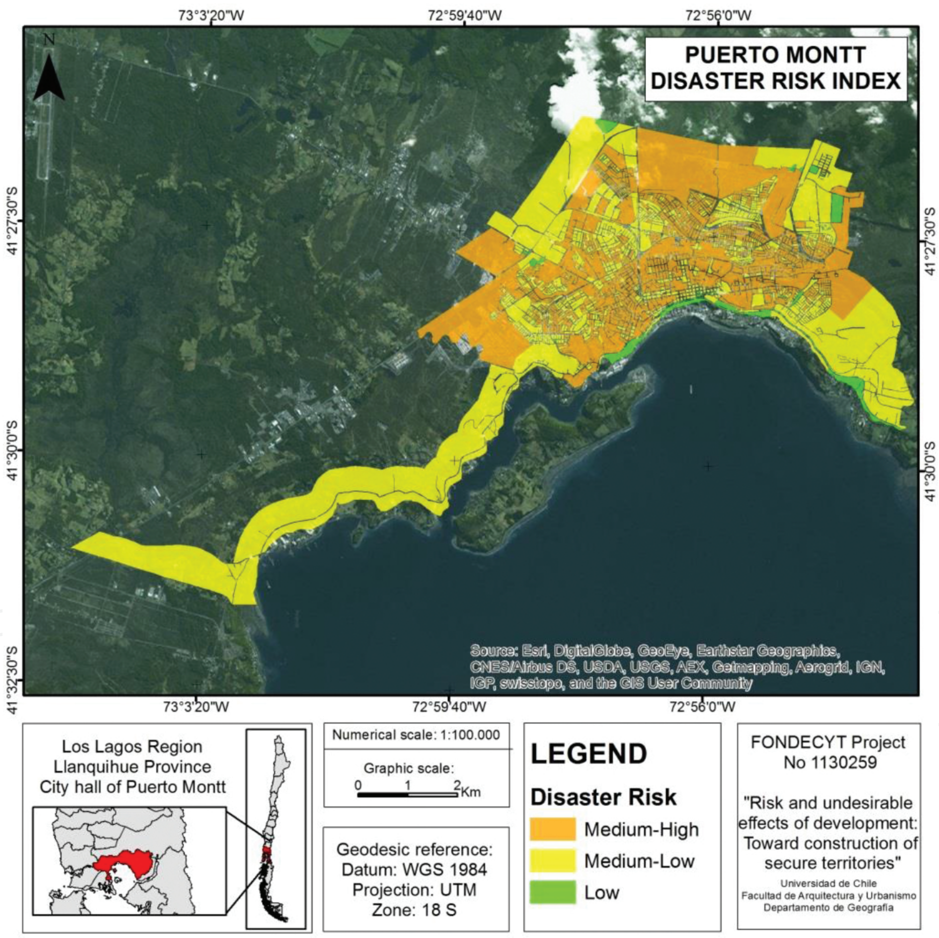


Figure 4. Disaster Risk Index (DRI), Puerto Montt City.

The city in general is exposed to seismic and volcanic hazards (volcanic ashes) and a low risk of tsunami. However, other recurring hazards of hydro-meteorological type affect the inhabitants throughout the year, causing small but cumulative impact resulting in deterioration of their health and quality of life.

5.4. Comparative analysis of the two cities: Puerto Varas and Puerto Montt

It is at the local level that risk is built and consequences of adverse events experienced. Hence our analysis recognizes the significance of conducting risk assessment at the local level, taking into account its main components (hazard, vulnerability, and exposure), to generate a significant differentiation between and within cities.

The assessment at the block level helps to improve decision-making regarding resource allocation for disaster risk reduction, as it identifies the most critical blocks for prioritization of intervention. At the same time, it is also possible to work on prospective risk management, addressing and seeking to avoid the construction of new or increased disaster risks, and defining the best options for the city expansion.

Table 8 shows a comparative analysis between the two cities evaluated with the same model (Puerto Varas and Puerto Montt). An “average” block or representative of each model H, E, PSV, and SR was selected as the arithmetic average of the values of the cells of each city to calculate the representative DRI.

Comparative analysis Of The Average Behavior Puerto Montt V/S Puerto Varas

	$\alpha 1$	Hazards	Exposure	$\alpha 2$	PSV	SR	DRI	Qualification
PuertoVaras	0.580	0.2820	0.4440	0.420	0.2570	0.3230	**0.2648**	Medium-low
Puerto Montt	0.580	0.4362	0.4857	0.420	0.2566	0.5120	**0.2430**	Medium-low
		54.6%	9.5%		0.2%	58.7%	**9.0%**	Differences (%)

Table 8. Comparative analysis of the average behavior: Puerto Montt v/s Puerto Varas.

In analyzing the above table, it can be seen that the perceived DRI Puerto Varas is 9.0% higher than that of Puerto Montt. Even though it seems counterintuitive at first (it is the general perception that Puerto Varas has a lower risk than Puerto Montt), the result is considered reasonable. The hazard in Puerto Montt (0.4362) is rated 55% higher than in Puerto Varas (0.282) but at the same time, the SR in Puerto Montt (0.5120), 59% higher than Puerto Varas (0.3230), compensates for the hazard.

Note that both E as well as PSV are almost the same in both cities (9.5% and 0.2% difference), making the overall difference indecisive.

In an analysis by rating of cell, it can be said that there is only 9% difference in the overall perceived disaster risk between the two cities. Puerto Montt has more cells qualified in medium-high risk than in Puerto Varas, but this is offset by the fact that Puerto Montt has several cells qualified as low risk cells, while Puerto Varas has none.

The perception that Puerto Varas’ hazards have less potential impact compared with Puerto Montt holds true. However, a comprehensive risk assessment considering all the variables reveals that the level of overall risk of Puerto Varas is higher, mainly due to social and subjective factors.

6. Conclusions

The result of each model as well as the perceived comprehensive DRI was represented cartographically (**Figures 2–4**), finding spatial patterns in the disaster risk level of the city and its explanatory variables (risk drivers). The DRI showed a clear spatial pattern in the cities—three zones of different risk levels are seen, predominantly medium-high level, in most of the consolidated urban area.

The result is the combination of the four models (hazards, exposure, PSV and SR) that were used for the evaluation of risk at the city block level, according to the weights set, representing the current or actual perceived risk of the cities. This complete model can also be used to build future disaster risk scenarios, using the possible values of the four models as parameters to analyze potential interventions and their ability to reduce risks.

The sensitivity analysis shows a high susceptibility of SR, demonstrating the need to focus efforts on improving the capabilities of self-protection and self-management of the population. Any change in these capabilities is first reflected in the population's perception, and then immediately in the overall disaster risk of the city.

The three cities analyzed have different levels of risk associated with their geographical location and hazards determined by the geological and morpho-climatic context. The risk also responds to social fragility situations such as poverty, lack of education, precarious housing, among others, as well as to the population's lack of capacity for self-development and self-management. These variables, aggravated by exposure of the population and their livelihoods to socio-natural hazards, result in a significant heterogeneity in disaster risk levels among and within the three cities analyzed.

The block-level modeling allows us to acquire detailed information about the factors that contribute to building disaster risk within the cities, informing the decision making process geared to reduce it. The variables considered are dynamic, vary in time and space, and most of them can be mitigated. The modeling of natural hazards can be generalized to different settlements with similar geographic conditions. The social vulnerability and SR variables must be locally analyzed as they present great variations that resulting in distinct disaster risk levels. The relevance of social risk construction and its future trends is acknowledged.

This comprehensive analysis allowed us to objectively measure the comprehensive DRI level of each city. When metrics allowed, we compared the results for the studied cities (Iquique, Puerto Montt and Perto Varas) using four individual models (H, E, PSV, and SR) as well as the comprehensive DRI average. This *holistic* assessment approach can be transferred to other cities, countries, and regions, allowing generic and standardized processes, while respecting unique local features.

Author details

Carmen Paz Castro[1], Juan Pablo Sarmiento[2] and Claudio Garuti[3*]

*Address all correspondence to: claudiogaruti@fulcrum.cl

1 Department of Geography, University of Chile, Santiago, Chile

2 Extreme Events Institute, Florida International University (FIU), Miami, USA

3 Fulcrum Engineering Ltd. (Decision making engineering), Santiago, Chile

References

[1] Adger, W. N., H. Eakin, and A. Winklels. 2009. Nested and teleconnected vulnerabilities to environmental change. *Frontiers in Ecology and the Environment* 7(3):150–157. doi: 10.1890/070148.

[2] Berkes, F., T. P. Hughes, R. S. Steneck, J. A. Wilson, D. R. Bellwood, B. Crona, C. Folke, L. H. Gunderson, H. M. Leslie, J. Norberg, M. Nyström, P. Olsson, H. Österblom, M. Scheffer, and B. Worm. 2006. Globalization, roving bandits, and marine resources. *Science* 311:1557–1558.

[3] Birkmann J., Fernando, N. 2008. Measuring revealed and emergent vulnerabilities of coastal communities to tsunamis in Sri Lanka. *Disasters* 32(1):82–104.

[4] Cardona, O. D. 2001. *[Comprenhensive risk assessment using complex dynamic systems]*. Universidad Politécnica de Catalunya,[Catalonia Polytechnic University] Barcelona, 232.p. 2001.[In Spanish]

[5] Castro-Correa, C. P. *[Environmental Risk Assessment in the Chilean semiarid's Urban Coastal Areas: Caldera]*. Tesis para optar al grado de Doctor, Universidad de Zaragoza, España, [Thesis for the PhD degree, University of Zaragoza, Spain] 2014. 497 pp.[In Spanish]

[6] Castro, C. P., Garuti, C. 2011. *Building an Index to Measure the Natural Risk Management in Latin-American Countries.* ISAHP-2011, Sorrento-Italy.

[7] Cuny, F. *Disasters and Development*. Oxford University Press, Oxford, England, U.K. 1983.

[8] Cutter, S., L. Barnes, M. Beny, C. Burton, E. Evans, E. Tale, and J. Webb. 2008. A place-based model for understanding community resilience to natural disasters. *Global Environmental Change* 18:598–606.

[9] Chardón, A. 2002. *[A geographical approach of vulnerability in urban areas exposed natural hazards, the Andean example of Manizales, Colombia]*, Manizales, Colombia. [In Spanish]Available: http://www.yorku.ca/ishd/CHARDON_04.pdf

[10] Dovers, S., Handmer, J. 1992. Uncertainty, sustainability and change. *Global Environmental Change* 2(4):262–276.

[11] Garuti, C., Escudey, M. 2005. *[Decision Making in Complex Scenarios]*, Publication of University of Santiago, Santiago-Chile. 420pp.

[12] Garuti, C., Sandoval, M. 2006. The AHP: A multicriteria decision making methodology for shiftwork prioritizing. *Journal of Systems Science and Systems Engineering* 15(2):189–200.

[13] Garuti, C., Spencer, I. 2007. Parallels between the analytic hierarchy and network processes (AHP/ANP) and fractal geometry. *Mathematical and Computer Modeling* 46(7–8):926–934. ISSN 0895–7177. ScienceDirect.

[14] Garuti, C., V. Salomon, and I. Spencer. 2008. A Systemic Rebuttal to the Criticism Of Using Eigenvector for Priority Assessment in The Analytic Hierarchy Process. *Computing and Systems, Iberamerican computing review, Mexico* 12(2):192–207.

[15] Garuti, C. 2012. *Measuring in Weighted Environments: Moving from Metric to Order Topology*. *(Knowing when close really means close)*. Universidad Santa Maria, Editorial USM, Santiago-Chile, 72 p.

[16] Gellert, G., Latin, A. 2012. El cambio de paradigma: de la atención de desastres a la gestión del riesgo. *[The paradigm shift: from disaster response to risk management] [Sapiens Scientific Research Bulletin]* 2(1): 13–17pp. 2012. [In Spanish]

[17] Henly-Shepard, S., Steven A. Gray, and L. J. Cox. 2015. The use of participatory modeling to promote social learning and facilitate community disaster planning. *Environmental Science & Policy* 45:109–122.

[18] Kabisch, S., A. Kunath, P. Schweizer-Ries, and A. Steinführer. 2011. Vulnerability, Risks, and Complexity, Impacts of Global Change on human Habitats. *Advances in People Environment Studies, Germany* 3:317.

[19] Manyena, S. 2006. *The Concept of Resilience Revisited. Disasters*, © Overseas Development Institute 30(4). Published by Blackwell Publishing, 9600 Garsington Road, Oxford, OX4 2DQ, UK and 350 Main Street, Malden, MA 02148, USA. 433-450 pp.

[20] Marinoni, O., Hoppe, A. 2006. Using The AHP process to support sustainable use of geo-resources in metropolitan areas. *Journal of Systems Science and Systems Engineering* 15(2):154–164. Technische Universität Darmstadt, Institute for applied Geosciences, Germany.

[21] Martínez, M. 2009. Los geógrafos y la teoría de riesgos y desastres ambientales. *[Geographers and the risk and environmental disaster theory]* 14:241–263.

[22] Matyas, D., Pelling, M. 2012. *Disaster Vulnerability and Resilience: Theory, Modeling and Prospective*. Report produced for the Government Office of Science, Foresight project 'Reducing Risks of Future Disasters: Priorities for decision makers'. 72 pp.

[23] Mayunga, J. S. *Understanding and Applying the Concept of Community Disaster Resilience: A capital-based approach*. A Draft Working Paper Prepared for the Summer Academy for Social Vulnerability and Resilience Building, 22–28 July 2007, Munich, Germany. Retrieved October 2011.

[24] Miller, F., H. Osbahr, E. Boyd, F. Thomalla, S. Bharwani, G. Ziervogel, B. Walker, J. Birkmann, S. Van der Leeuw, J. Rockström, J. Hinkel, T. Downing, C. Folke, and D. Nelson. 2010. Resilience and vulnerability: complementary or conflicting concepts? *Ecology and Society* 15(3):11. [online] URL: http://www.ecologyandsociety.org/vol15/iss3/art11/

[25] Olcina, J. 2008. *[Changes in the territorial, conceptual and method of natural hazards considerations]*. In X International Colloquium Geocrítica, Ten years of changes in the world, in geography and social sciences, 1999–2008. Barcelona. 2008.[In Spanish].

[26] Saaty, T., Vargas, L. 1994. *Decision Making in Economic, Political, Social and Technological Environments. With the Analytic Hierarchy Process*. RWS Publications, USA. 325 p.

[27] Saaty, T. 1996. *Decision Making for Leaders*. RWS Publications, USA. 315 p.

[28] Saaty, T., Peniwati, K. 2008. *Group Decision Making. Drawing Out and Reconciling Differences.* RWS Publications, USA. 385 p.

[29] Siddayao, Generino P., Sony E. Valdez, and Proceso L. Fernandez. 2014. Analytic Hierarchy Process (AHP) in Spatial Modeling for Floodplain Risk Assessment. *International Journal of Machine Learning and Computing* 4(5):450–457. doi:10.7763/IJMLC.2014.V4.453.

[30] Wachinger, G., Renn, O. 2010. Risk Perception and Natural Hazards. CapHaz-Net WP3 Report, DIALOGIK Non-Profit Institute for Communication and Cooperative Research, Stuttgart. [online] URL: http://caphaz-net.org/outcomes-results/CapHaz-Net_WP3_Risk-Perception.pdf

[31] Whitaker, R. Validation examples of the AHP and ANP. 2007. *Mathematical and Computer Modeling* 46(7–8):840–859.

[32] Yamin, L. E., F. Ghesquiere, O. D. Cardona, and M. G. Ordaz. 2013. *[Probabilistic modeling for disaster risk management: the case of Bogotá, Colombia]*. Banco Mundial, Universidad de los Andes. [World Bank, Universityof the Andes] 188pp. 2013. [In Spanish].