

Estimation of the Risk Management Index (RMI) using statistical analysis

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Abstract Based on a statistical analysis, we developed a methodology to determine the Risk Management Index (RMI) at the local level. The algorithm is transparent, relatively easy to update periodically by the affected communities themselves, and the results are easy to understand by public policymakers. The main characteristics of this tool are: (1) It considers disaster management issues at the local level; (2) RMI values are obtained using a statistical analysis; (3) levels of performance are classified in a scale of numbers ranging from 0 to 5, where 0 = *nonexistent*, 1 = *low*, 2 = *incipient*, 3 = *significant*, 4 = *outstanding*, and 5 = *optimal*; (4) the weight of the indicators is determined using the analytic hierarchy process. As case studies we applied this methodology to the districts of Iztapalapa and Xochimilco in Mexico City, Mexico. Our results indicate that, to date, the Xochimilco District has not implemented any actions designed to reduce risk or to provide financial protection. Low performance was measured also in risk identification and disaster management. The Iztapalapa District has an outstanding level of performance in risk identification. However, its score is low in activities related to risk reduction, disaster management, and financial protection. The RMIs obtained in both communities highlight the need for developing permanent programs for disaster prevention, mitigation, and response. The methodology used here is designed to aid in evaluating and understanding existing disaster management problems in a community and in guiding the decision-making processes to reduce the hazard and to conduct remedial actions at the local level.

Keywords Risk management · Risk Management Index · Natural hazards · Vulnerability · Risk

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1 Introduction

Natural hazards are threatening events capable of producing damage to the physical and social space where they take place, not only at the moment of their occurrence, but on a long-term basis due to their associated consequences. When these consequences have a major impact on society and/or infrastructure, they become disasters (Alcantara-Ayala 2001). The degree and extent of a disaster depends mainly on the existing social conditions of the affected community (Smith 2001). Thus, reducing disaster risk in a particular locality requires the assessment of the hazard level and of the various types of vulnerabilities associated with it: i.e., economical, social, environmental. Hazards are often grouped into three main categories, according to their causes: natural (earthquakes, hidrological phenomena, landslides, etc.), technological (explosions, release of toxic material, etc.), and anthropogenic (terrorist activity, crowd related, etc.) (Schneiderbauer and Ehrlich 2006).

Vulnerability is a function of the sensitivity or susceptibility of a system (community, household, building, infrastructure, nation, etc.) to be affected or damaged by a certain hazard. A vulnerability assessment needs to include both quantitative and qualitative methods to describe it and design a response to it (Birkmann and Wisner 2006). A comprehensive compilation of various approaches to measure vulnerability and risk at different levels can be found in Birkmann (2006).

Disaster risk management requires what is called “risk dimensioning” (Cardona et al. 2003). This means that one needs to take into account not only factors such as the expected physical damage, the number of victims, and the economic equivalent loss, but also the social, organizational, and institutional impacts. Because most existing indices and evaluation techniques do not express risk in understandable and accessible terms that are adequate for decision-makers, in this work we develop a methodology to determine the Risk Management Index using basic statistics analysis instead of the fuzzy sets as proposed by Cardona et al. (2003) and applied in various communities and countries of the Americas by the Institute of Environmental Studies, National University of Colombia—Manizales, under the auspices of the Inter-American Development Bank (IADB-UNC/IDEA 2005). We believe that measuring risk management needs to take into account the specific context of the country and the broader livelihood framework, in which vulnerable people are embedded at the local level. To this end, our methodology is easy to understand and straightforward to apply on a regular basis by local authorities of small communities. As cases of studies we apply this method to the districts of Iztapalapa and Xochimilco of Mexico City, Mexico.

2 Methodologies to estimate risk and vulnerability indices

Risk indices should take into account the physical aspects of risk as well as the non-physical aspects, such as the economic capacity of the community, the ability of the population to protect itself, the social structure and its organizational levels, and governance capacities, among others (Cardona et al. 2003). Performance benchmarks also need to be established in order to facilitate decision-makers’ access to relevant information as well as the identification and evaluation of effective policies and actions.

In recent years, an increasing number of global and local initiatives have been launched to measure risk and vulnerability (e.g., Birkmann 2006, 2007). Three major global projects have been carried out to measure risk and/or vulnerability with the help of indicators and

indices at the national scale, and for international and global comparisons. These include the United Nations Development Programme (UNDP)'s Disaster Risk Index (DRI) (UNDP 2004), the Hotspots Project by Columbia University (Dilley et al. 2005), and the program to obtain Indicators of Disaster Risk and Risk Management for the Americas (IADB-UNC/IDEA 2005).

The DRI is designed to make a quantitative comparison of disaster risk between countries exposed to specific hazards. Although the resulting impact of disasters varies from hazard to hazard, it is important to select key indicators that may be useful in comparing disaster risk between countries and also between hazard types. Furthermore, the DRI was developed to outline the relationship, in which economic and social development influences disaster risk and vulnerability (UNDP 2004).

The Hotspots Project carried out primarily by Columbia University, in co-operation with the World Bank and other institutes, develops a world map of hotspots, i.e., a global map showing where the risk of mortality and economic losses due to hazards of natural origin is greater. This approach focuses primarily on risk as a product of hazard frequency and its associated consequences. The goal of the Hotspots Project was to provide insights on worldwide disaster risk patterns in order to improve disaster preparedness and the prevention of losses (Dilley et al. 2005).

Cardona et al. (2003) developed a conceptual framework and a model for risk analysis of a city, based on a holistic perspective and describing risk by means of indices. He considered both “hard” and “soft” risk variables of the urban centers, taking into account exposure, socioeconomic characteristics of the different areas or neighborhoods of the city, and their disaster-coping capacity or degree of resilience. One of the objectives of this model was to guide the decision-making process of risk management, helping to identify critical zones of a city and their vulnerability from the perspective of different professional disciplines.

The purpose of the assessment of the IADB-UNC/IDEA (2005) program based on the methodology developed by Cardona et al. (2003) was to: (1) assist policy makers in identifying investment priorities to reduce risk; (2) identify national risk management capacities and evaluate the effects of policies and investments on risk management; (3) promote the exchange of information; and (4) gauge a country's relative position in disaster management and compare its evolution over time.

The IADB-UNC/IDEA (2005) methodology considers four main indices: the Disaster Deficit Index, the Local Disaster Index, the Prevalent Vulnerability Index, and the Risk Management Index. Each index is composed of a number of indicators with a total number of more than 50 of them.

The index that is the objective of this work, and for which we propose a straightforward methodology to estimate it, is the *Risk Management Index* (RMI). The RMI brings together a group of indicators that measure a country's risk management performance. It measures the operation of key services, the institutional capacity to face disasters, and the effectiveness of basic risk management instruments such as risk identification, prevention and mitigation measures, financial mechanisms to reduce the impact of disasters, the emergency response levels, and its preparedness and recovery capacity.

The RMI is based on six qualitative components, which are evaluated by experts in the community under study (IADB-UNC/IDEA 2005). This methodology considers five levels of performance for each indicator of RMI: *low*, *incipient*, *significant*, *outstanding*, and *optimal*. Such linguistic qualitative values, according to the proposal of Cardona et al. (2003), are the same as a fuzzy set that have a membership function of the bell or sigmoidal type (at the extremes). This approach pioneered the use of performance indices to estimate

the preparedness of a community to a potential disaster. Using these bell and sigmoidal functions, a physical risk index and qualification are obtained by means of the union and subsequent defuzzification, applying the method of the centroid of the area (COA) of the group of descriptors (Cardona et al. 2003). Whereas this methodology for estimating performance indices has the advantage of being composed of measures that directly map specific decisions and/or activities designed for risk identification and reduction, disaster management, and governance and financial protection, the methodology has two important drawbacks. First, it is not an open system, and the algorithm is not openly available in a way that would allow cities and communities to apply it themselves and track their progress. Secondly, the formulation is mathematically and conceptually complex, and it is difficult to explain to laymen in the communities and to decision-makers.

Because of the reasons pointed out above, we propose a more straightforward approach to estimate RMIs. The methodology is simpler and easier to apply by the communities. It is designed as a tool that communities and cities may apply themselves in order to benchmark their progress and tackle their drawbacks. Finally, and very importantly, we demonstrate that our methodology yields essentially the same results as the IADB-UNC/IDEA (2005) tool.

3 Methodology to determine the Risk Management Index using statistical analysis (RMIS)

In this work, as in the IADB-UNC/IDEA method (2005), we use the analytic hierarchical process (Saaty and Vargas 1991) to determine the weights (w_i) of the indicators of the four composite indices. However, we determine the RMI using basic statistical analysis, as described below. With the purpose of developing sub-indicators to apply at the local level, we modified and expanded those proposed by IADB-UNC/IDEA (2005) as follows:

3.1 Sub-indicators of risk identification (RMI_{RI})

1. *RI1*. Inventory of municipal disasters and associated losses
2. *RI2*. Hazard monitoring
3. *RI3*. Availability and updating of hazard maps
4. *RI4*. Assessment of risk and vulnerability
5. *RI5*. Public information and community participation
6. *RI6*. Education and training in integral risk management

3.2 Sub-indicators of risk reduction (RMI_{RR})

1. *RR1*: (a) Consideration of risk analyses in the local development program; (b) existing land-use regulations; (c) existing regulations for housing and building construction
2. *RR2*: (a) Watershed management; (b) environmental sustainability
3. *RR3*: Implementation of disaster mitigation actions
4. *RR4*: (a) Retrofitting of exposed housing and buildings; (b) resettlement of exposed communities
5. *RR5*: Updating and enforcement of construction regulations and codes
6. *RR6*: Programs for the reduction in structural vulnerability of public and private critical facilities

3.3 Sub-indicators of disaster management (RMI_{DM})

1. *DM1*: Organization and coordination of local disaster response
2. *DM2*: (a) Local plans for disaster response and development of early warning systems; (b) existing sectorial disaster response plans
3. *DM3*: Endowment of equipment, tools and infrastructure for disaster response
4. *DM4*: Inter-institutional and local drills for disaster response
5. *DM5*: Local preparedness and training for disaster response
6. *DM6*: Existing rehabilitation and reconstruction plans

3.4 Sub-indicators of governance and financial protection (RMI_{FP})

1. *FP1*: Establishment of local committees for risk management with inter-institutional and multi-sectorial participation
2. *FP2*: Annual budget for operation of the local structure for disaster management
3. *FP3*: Existing external technical and financial cooperation (national or international)
4. *FP4*: Existing social networks for disaster response
5. *FP5*: Government insurance for risk transfer
6. *FP6*: Insurance and re-insurance for the housing, industrial, and commerce sectors

All these sub-indicators are evaluated by the community, considering six performance levels: *nonexistent*, *low*, *incipient*, *significant*, *outstanding*, and *optimal*. For data processing, the following values are considered to these levels:

- Nonexistent: 0
- Low: 1
- Incipient: 2
- Significant: 3
- Outstanding: 4
- Optimal: 5

It is important to point out that the IADB-UNC/IDEA (2005) methodology does not consider the *nonexistent* level. In our case, this level with a value of 0 indicates that the community does not report or conduct activities related to the sub-indicator in question. In our experience, this is unfortunately the status for some indicators, and it needs to be reflected in this manner. In some cases, the sub-indicator is composed of two or three sub-indicators identified by *a*, *b*, and *c*. This categorization for some sub-indicators was designed with the purpose of identifying important risk elements at the local level.

Once established our theoretical conceptual framework, the following methodology was established for data processing and analysis:

3.5 Step 1: Data collection

During workshops, the local authorities responsible for disaster response, prevention, and mitigation as well as those decision-makers in charge of implementing sustainability and development programs of the analyzed community must establish the levels of performance (0–5) for each component of each sub-indicator (RMI_{RI} , RMI_{RR} , RMI_{DM} , RMI_{FP}).

3.6 Step 2: Establishment of weights (w_i) for each component of each sub-indicator

As in Cardona et al. (2003), each sub-indicator is weighted using the AHP process (Saaty and Vargas 1991). The AHP is a structured technique for organizing and analyzing complex decisions, based on mathematical and psychological principles. It provides a comprehensive and rational framework for structuring a decision-making process by representing and quantifying its elements, relating those elements to overall goals, and evaluating alternative solutions. In our case, the local authorities are requested to evaluate systematically all sub-indicators of RMI by comparing them to one another, two at a time, and evaluating their impact on their plans for disaster prevention, mitigation and response. In making these comparisons, the decision-makers are requested and encouraged to use concrete data and information about the sub-indicators. However, they normally use their judgment about the relative meaning and importance of these sub-indicators. Because of this, the purpose of using AHP is to take into account human judgments, and not simply the underlying information that is used to obtain numerical weights (w_i) for each sub-indicator.

The AHP is a flexible and powerful tool because the weights and, therefore, the final ranking of the sub-indicators, are obtained on the basis of the pairwise relative evaluations of both the criteria and the options provided. The computations made by the AHP are always guided by the decision maker's experience, and the AHP can thus be considered as a tool that is able to translate the evaluations (both qualitative and quantitative) made by the decision maker into a multicriteria ranking. In addition, the AHP is simple because there is no need of building a complex expert system with the decision maker's knowledge embedded in it, and it can be implemented in three simple consecutive phases: (1) Computing the vector of criteria weights; (2) Computing the matrix of option scores; and (3) Ranking the options (Saaty and Vargas 1991).

3.7 Step 3: Data processing

With the purpose of developing a friendly and accessible tool for its application at the local level, all components of the RMI (RMI_{RI} , RMI_{RR} , RMI_{DM} , RMI_{FP}) are estimated using a weighted average of each sub-indicator:

$$RMI_{RI} = \frac{\sum_{i=1}^6 w_i RI_i}{\sum_{i=1}^6 w_i} \quad (1)$$

$$RMI_{RR} = \frac{\sum_{i=1}^6 w_i RR_i}{\sum_{i=1}^6 w_i} \quad (2)$$

$$RMI_{DM} = \frac{\sum_{i=1}^6 w_i DM_i}{\sum_{i=1}^6 w_i} \quad (3)$$

$$RMI_{FP} = \frac{\sum_{i=1}^6 w_i FP_i}{\sum_{i=1}^6 w_i} \quad (4)$$

where w_i is the weight obtained using the AHP as described above and RI_i , RR_i , DM_i , FP_i represent any value between 0 and 5 assigned to each sub-indicator (as explained above). It is important to point out that in the case of those sub-indicators with more than one

variable (a , b , c), the value of the sub-indicator is obtained from the average of these variables (considering their corresponding w_i).

Finally, as in IADB-UNC/IDEA (2005), the total RMI is obtained from the average of the four composite sub-indicators:

$$\text{RMI} = (\text{RMI}_{\text{RI}} + \text{RMI}_{\text{RR}} + \text{RMI}_{\text{DM}} + \text{RMI}_{\text{FP}})/4 \quad (5)$$

A summary of the main differences of the methodology developed here to that developed by Cardona et al. (2003) and IADB-UNC/IDEA (2005) are the following:

1. The system of sub-indicators was modified to make it applicable and to take into account issues at the local level (instead of country level).
2. The qualification for each descriptor is obtained by means of statistical analysis (instead of fuzzy sets).
3. Levels of performance are classified and presented in a scale of numbers ranging from 0 to 5 (instead of 0 to 100), where *low* = 1, *incipient* = 2, *significant* = 3, *outstanding* = 4, and *optimal* = 5. In our methodology, we introduce a value of 0 representing complete lack of actions or information.
4. The weight of the indicators is determined from the expert opinions of the local communities, instead of using the same weights estimated at the country level. In this way, each community identifies and classifies their own factors that are most critical for disasters response, reduction, and prevention, and weights are assigned accordingly.

We believe that with our methodology, the system of indicators provides the appropriate evaluation tools that are necessary to understand the problem and guide the decision-making process at the local level. The “Risk Management Index using Statistical Analysis (RMIS)” methodology developed here is a simple and straightforward approach that identifies the needs to reduce risk to natural hazards. The process is transparent and allows the affected communities to update their RMI periodically by themselves. The main objective is to encourage and assist small communities in their efforts to reduce their vulnerability to various hazards.

4 Comparison between the IADB-UNC/IDEA and RMIS methodologies

To compare our methodology to that developed by IADB-UNC/IDEA, we applied RMIS to the same data set reported for the city of Manizales, Colombia, by Suárez-Olave et al. (2007). These authors estimated the RMI using the IADB-UNC/IDEA method. Our analysis demonstrates that practically both methodologies generate essentially the same results. Values of RMI_{RI} , RMI_{RR} , RMI_{DM} , RMI_{FP} follow the same tendency during the period of study (Fig. 1). In fact, the behavior of the values obtained for the RMI index is practically the same with both methods (Fig. 2).

Risk identification in Manizales increases systematically as a function of time (Fig. 1). For the years 1990 and 1995, the levels of performance were *low* and *incipient*, respectively. Then, from 2000 to 2005, RMI_{RI} increased from a value of *significant* to an *outstanding* level of performance (Fig. 1a, aa). Between 1990 and 1995, risk reduction in this community had a *significant* level of performance in disaster management. In the year 2000, RMI_{RR} increased significantly and advanced in 2005 up to the *optimal* level of performance (Fig. 1b, bb).

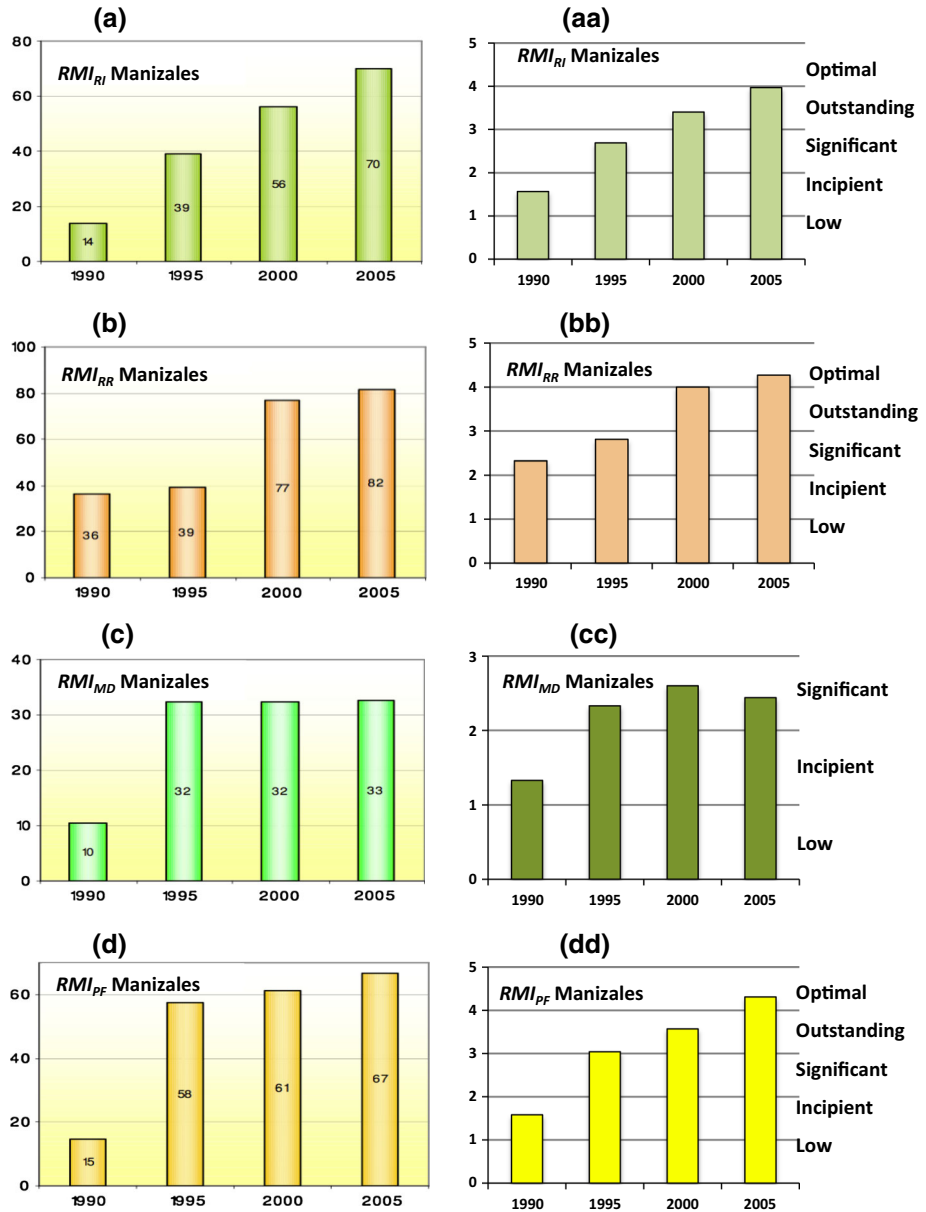


Fig. 1 Values of the sub-indicators of RMI for the city of Manizales, Colombia. Columns **a–d** results reported by Suárez-Olave et al. (2007) using the IADB-UNC/IDEA methodology; columns **aa–dd** results using the RMIS method

Disaster management policy in Manizales greatly improved in the year 1995 and maintained this level until 2005. In 1990, all sub-indicators had a level of performance between *low* and *incipient* and in 1995 RMI_{DM} reached the *significant* level that remained until 2005 (Fig. 1c, cc). In the case of financial protection, in 1990 this community initiated

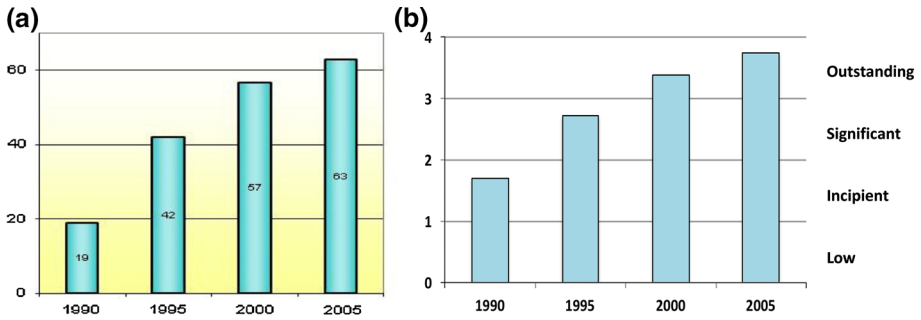


Fig. 2 Values of RMI for the city of Manizales, Colombia. **a** Results reported by Suárez-Olave et al. (2007) using the IADB-UNC/IDEA methodology; **b** results using the RMIS method

with an *incipient* level of performance; however, RMI_{FP} progressed significantly in 1995 increasing to the *optimal* level in 2005 (Fig. 1d, dd).

The total RMI (Eq. 5) increased significantly since the year 1995 in Manizales, and it kept increasing until the year 2005 reaching an *outstanding* level of performance (Fig. 2a, b). This is mainly because of the great performance in risk reduction followed by risk identification and financial protection during the last two periods. Disaster management, however, is the component with minor progress, in which the community should improve (Fig. 1c, cc).

As pointed out above, very similar conclusions as those stated above can be reached using the IADB-UNC/IDEA or the RMIS method. Thus, we confirm that both tools measure the same levels of performance for the city of Manizales. To complete the validation of RMIS, we performed other tests using data from others reports of RMI values estimated by applying the IADB-UNC/IDEA methodology (e.g., Cardona 2007; IADB 2011). In all cases, we obtained similar and comparable results (not shown here). Thus, we conclude that the methodology developed here generates indicators that are robust and representative and measure a community’s risk management performance in a manner which is both simpler and more straightforward to understand by local communities than the IADB-UNC/IDEA method.

5 Case studies

After the 1985 destructive seismic event (UNAM Seismology Group 1986), Mexico’s authorities promoted various initiatives to build resilience to natural disasters. The first step was the creation in 1986 of the National Civil Protection System (Sistema Nacional de Protección Civil; SINAPROC). To assure financing for SINAPROC’s activities, the Natural Disaster Fund (Fondo de Desastres Naturales, FONDEN) was created in 1996, followed in 2003 by the Natural Disaster Prevention Fund (Fondo para la Prevención de Desastres Naturales, FOPREDEN). Both initiatives are managed by the Mexican National Center for Disaster Prevention (CENAPRED). These funding mechanisms have moved the national disaster risk management strategy from a system based on response, recuperation, and reconstruction to a system focused on preventive actions.

Although these actions and policies have achieved good results, authorities have recognized the need to continue improving disaster risk management. Under this framework, all government districts, municipalities, and states in Mexico must identify those natural and man-made risks to which they are exposed and design specific tools for hazard identification and vulnerability analysis. All of these are designed with the purpose of implementing disaster response and prevention actions. Thus, by law, all local governments in Mexico have a Disaster Management or Civil Protection Office. Nevertheless, there is no ongoing evaluation of the performance and impact of the policies implemented to reduce risk. We propose that the estimation of RMI would constitute a valuable tool to aid communities to measure their weaknesses and strengths and chart their progress and failures.

With the purpose of illustrating the application of the methodology developed here as well as evaluating their actual disaster management performance, we considered as case of studies the districts of Xochimilco and Iztapalapa in Mexico City, Mexico. These districts are two of the 16 boroughs within the Mexican Federal District. The data for our analysis

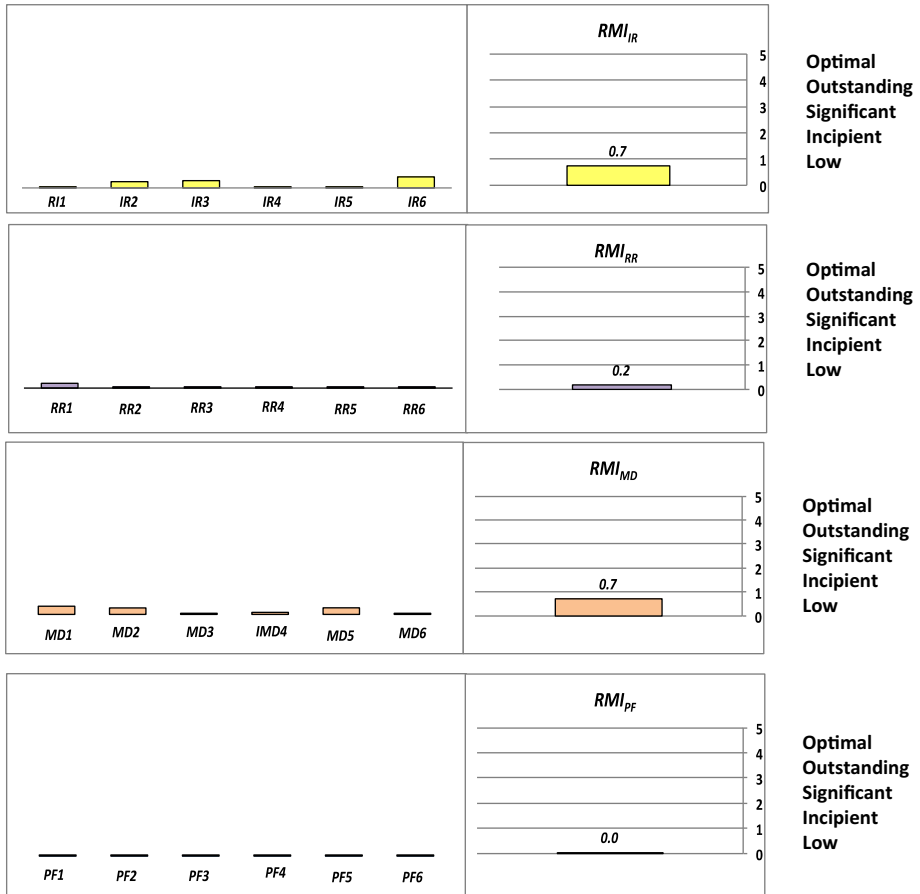


Fig. 3 Values of RMI_{IR} , RMI_{RR} , RMI_{DM} , RMI_{FP} for the Xochimilco borough, Mexico City, Mexico

were collected by direct interviews to local officials from these districts responsible for disaster prevention and mitigation actions.

Xochimilco is best known for its canals, which are remnants of what was an extensive lake and canal system that existed in the Valley of Mexico in pre-Columbian times. This borough extends over 125 km², accounting for 8.4 % of the Federal District’s territory. According to the 2010 census, its population was 415,007 inhabitants in that year, or 4.7 %

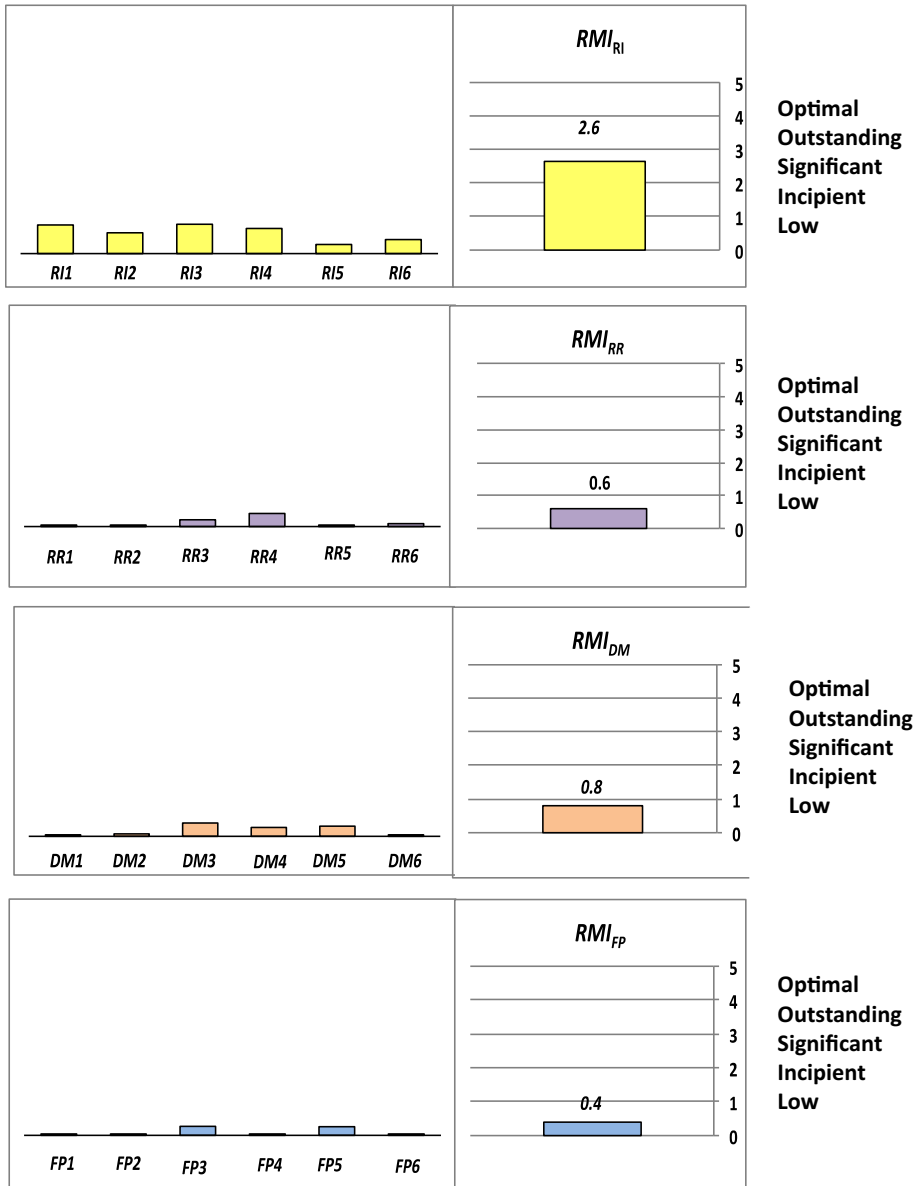


Fig. 4 Values of RMI_{RI}, RMI_{RR}, RMI_{DM}, RMI_{FP} for the Iztapalapa borough, Mexico City, Mexico

of Mexico City's total population. Since the pre-Hispanic period, Xochimilco's economy has traditionally been based on agriculture (<http://www.inegi.org.mx/>).

With a population of 1.8 million, as of the 2010 Mexican census, Iztapalapa is the most populous borough of Mexico City. Over 90 % of its territory is urbanized, and its people are mainly employed in commerce, services, and industry. Iztapalapa has a territory of about 117 km². Today, this borough has one of the highest population densities in Mexico and suffers from limited infrastructure and high levels of socioeconomic marginalization (<http://www.inegi.org.mx/>).

The majority of the territories of both Xochimilco and Iztapalapa are located on the lakebed zone where Mexico City was built. Also, because of their geographical, geological, and hidrological conditions, Xochimilco and Iztapalapa are highly exposed to land subsidence and local faulting (fracturing), as well as to the recurrent earthquakes, mainly from the Mexican subduction zone. Land subsidence is generally related to the consolidation of fine-grained materials in response to effective stress increments caused by extensive extraction of groundwater.

The results of our RMI analysis indicate that, to date, the district of Xochimilco has implemented very limited actions for risk reduction ($RMI_{RR} = 0.2$) and essentially no activities for financial protection ($RMI_{FP} = 0.0$). *Low* performance was identified for actions related to risk identification ($RMI_{RI} = 0.7$) and disaster management ($RMI_{DM} = 0.7$) (Fig. 3). The most recurrent natural phenomenon to which Xochimilco is exposed is land subsidence and fractures as well as floods. Less recurrent events are earthquakes and volcanic eruptions, although they may represent a very high risk for the exposed population. The very low performance in risk management identified for this district indicates its need to develop short- and medium-term projects and programs to identify the existing levels of risk (hazard and vulnerability) to which its population is exposed and to implement the necessary management actions for disaster prevention, mitigation, and response. Among these actions are monitoring land subsidence and implementing preventing measures for the affected population, developing programs for land use according to the spatial distribution of risk, and deploying early warning systems in critical facilities. In particular, for the areas of Xochimilco located on the ancient lakebed, the development of protocols and procedures for using the Seismic Alert System of Mexico City (SAS) should be a priority (Suárez et al. 2009).

The Iztapalapa District has a *significant* level of performance in risk identification ($RMI_{RI} = 2.6$) (Fig. 4). This is due to the fact that in Iztapalapa, the local governments fund, a Center for Geological Risk Assessment, the only one in the 16 districts in Mexico

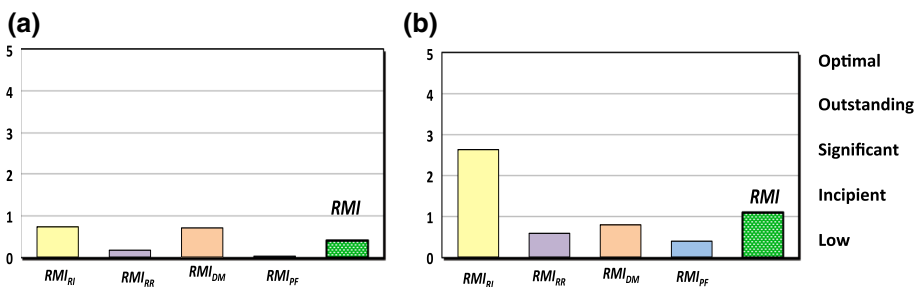


Fig. 5 Values of RMI (green rectangle) and its four sub-indicators for the districts of **a** Xochimilco and **b** Iztapalapa in Mexico City, Mexico

City. In contrast, its performance is *low* in activities of risk reduction ($RMI_{RR} = 0.6$), disaster management ($RMI_{DM} = 0.8$), and financial protection ($RMI_{FP} = 0.4$). These results indicate that as in the case of Xochimilco, it is necessary for Iztapalapa to implement projects and programs for disaster reduction and prevention including land-use regulations, monitoring local soil fissures, and installing seismic monitoring systems. Also, it is important to strength its performance in risk identification with the purpose of reaching in the future levels of *outstanding* and *optimal* in this sub-indicator.

Considering Eq. (5), the $RMI = 1.1$ for Iztapalapa is larger than that for Xochimilco $RMI = 0.4$ (Fig. 5). Thus, the level of performance in risk management for Iztapalapa is *incipient*, and for Xochimilco, it can be described only as *low*. In general, the district of Iztapalapa has a better level of performance than Xochimilco, mainly in risk identification (RMI_{RI}) but also in risk reduction (RMI_{RR}) and financial protection (RMI_{FP}). However, both districts have a similar and *low* performance in disaster management (RMI_{DM}) (Fig. 5).

6 Conclusions

Although all methodologies to estimate RMI have limitations and advantages that reflect the complexity of measuring the level of risk management of a community, we demonstrate that the methodology developed here generates comparable results as those of IADB-UNC/IDEA (2005) and that produces indicators that are transparent, robust, representative, replicable, comparable, and easy to understand. The system's main advantage lies in its ability to disaggregate results and identify factors that should be considered as priorities in risk management actions at the local level, while measuring the effectiveness of those actions. The most important contribution of this methodology is that it provides the opportunity to local decision-makers to initiate a systematic procedure of measuring and documenting their advances and needs in risk management.

As an example of the usefulness of RMIs, our results give a clear insight into the Xochimilco and Iztapalapa districts, as to where future work needs to be focused on disaster response and prevention actions. Xochimilco has not implemented any actions for risk reduction or financial protection. *Low* performance was identified for activities related to risk identification and disaster management. The Iztapalapa District has a *significant* level of performance in risk identification. However, its performance is *low* in activities of risk reduction, disaster management, and financial protection. In both districts, it is necessary to implement specific projects to reduce the level of risk and strength their disaster management program. We consider that our overall procedures used to estimate their RMI assure a very reasonable level of accuracy and veracity of the results for both districts.

In conclusion, in Mexico, and other disaster-prone regions, it is fundamentally important to implement a program that allows municipalities to learn how to collect data, analyze, and process the information, as well as to interpret the RMI values using a simple and straightforward methodology that disaggregates the results and identifies the different factors influencing risk. Programs and public policies designed to reduce risk at any level need to be periodically evaluated to estimate their effectiveness, enhance their benefits, and correct their shortcomings.

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Risk Management Index as case studies. We thank M. Viesca-Gold for her help in processing the data and preparing the initial figures. The project received grants from the Instituto de Geofísica and the Program to Support Research Projects and Technology Innovation of the National Autonomous University of Mexico (UNAM; PAPIIT Project No. IN118614).

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