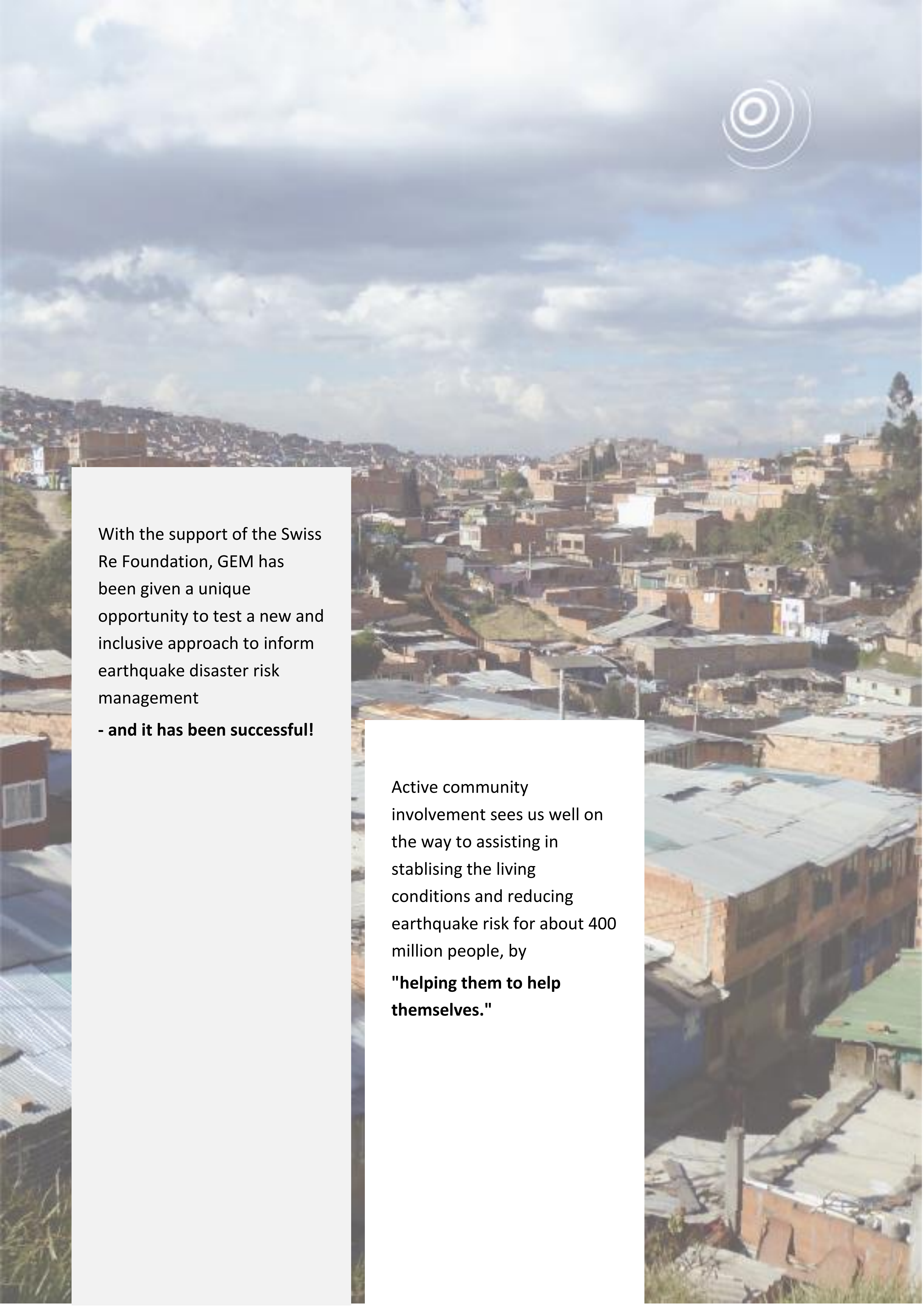
A report to the

Swiss Re Foundation

On the South America Risk Assessment (SARA) project
2013 - 2015



With the support of the Swiss Re Foundation, GEM has been given a unique opportunity to test a new and inclusive approach to inform earthquake disaster risk management

- and it has been successful!

Active community involvement sees us well on the way to assisting in stablising the living conditions and reducing earthquake risk for about 400 million people, by

"helping them to help themselves."

Final Report

South America Risk Assessment (SARA) Project

Version: [01]

Authors: GEM Secretariat

Date: December 2015

The GEM Foundation has made every effort to ensure the accuracy of the scientific and technical data, and the information in this report. Since the SARA implementation, however, involved many individuals, organizations and stakeholders from ten countries in the region, the GEM Foundation cannot guarantee complete accuracy.

Citation: **GEM Secretariat** (2015) South America Risk Assessment (SARA) Final Report 2015, Version 1.0., December 2015. SARA Project,

www.globalquakemodel.org

PREFACE

United Nations
Educational, Scientific and
Cultural Organization

Worldwide, earthquakes cause many fatalities and significant economic losses every year and pose considerable risks to livelihoods. It is within this context that the biggest proportion of human losses due to natural hazards is caused by earthquakes. During the second half of the century, building collapse caused more than 75 % of the total number of earthquake fatalities. South America is particularly vulnerable to earthquakes where some of the most noteworthy seismic events on record occurred in the last decade.

The need to improve the understanding of seismic risk in South America at the local, national and regional scale is therefore a necessity, in order to better draw strategies aiming to reduce the alarming levels of vulnerability to earthquake losses in the region. There is also a need for evidence-based science to support policy decisions to reduce earthquake risk and for the development of methods and tools that provide insight into the degree to which the built environment and populations are susceptible to adverse earthquake impacts and loss. UNESCO welcomes this report on the South American Risk Assessment (SARA) project as it addresses such issues and together with the GEM Foundation believes that as a result of the comprehensive, rigorous, open, and inclusive processes articulated here, real action to mitigate the risk can be achieved.

Through its contribution to the Sendai Framework for Disaster Risk Reduction 2015-2030 – notably to the Priority 1: Understanding Disaster Risk – the SARA project is to be commended for its clear view of the vulnerability, capacity, exposure of persons and assets, hazards characteristics and the environment of the South American region.

UNESCO will build synergies between the outputs of the SARA project with other initiatives it is implementing in the region, such as the Enhancing Natural HAzards resilience iN South America (ENHANS) project. As the UN Agency mandated in Education, Sciences and Culture UNESCO will support governments to address a number of challenges discovered through the implementation of the SARA project and fill related capacity gaps identified. Further, regional models produced by SARA can not only be utilized as backbone models for national seismic and risk maps and local risk assessments in the region, but also in other parts of the world. UNESCO believes that building resilient communities requires among other factors, well informed citizens and capacitated policy and decision makers, equipped with scientific information explained in simple terms and that is easy to be used. GEM's approach to promote sustainability by capacity development, institutional strengthening, and stakeholder engagement has been fundamental in achieving the aforementioned goals.

As a United Nations entity, UNESCO is engaged in the conceptual shift in thinking away from post-disaster reaction towards pre-disaster action and recommends that the outcomes of this report be used by national and local governments, as well as by regional and international organizations as milestones for future work on disaster risk reduction.

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Disaster Risk Reduction and Resilience Section on Earth
Sciences and Geo-Hazards
Risk Reduction Natural Sciences Sector, UNESCO, Paris.

EXECUTIVE SUMMARY

Within this document, the GEM Foundation presents its report to the Swiss Re Foundation on its South American Risk Assessment (SARA) project. An integrated and collaborative assessment of seismic risk in South America, SARA represents the completion of the first multi-country, regional project managed by the GEM Secretariat in Pavia. It is a prime example of how tangible progress in planning for disaster risk reduction at all scales – regional, national and local - can be achieved by integrating local expertise, highly advanced and transparent hazard and risk assessment technology, and local capacity development.

To quote the original proposal submitted to the Swiss Re Foundation in 2012:

> ***"Our goal in this 3-year, 1M€ project is to calculate South America' seismic hazard and risk, and to quantitatively estimate compounding social and economic factors that amplify the physical and post-event incapacities of communities within the region. This will be carried out using more uniform datasets and methodologies than have ever been attempted, using GEM's new open-source software engine, OpenQuake.***
>
> ***Equally important, GEM will engage national scientists and engineers throughout South America, as well as national and regional scientific, governmental and non-governmental institutions to participate at all levels of the data gathering and risk modeling. Therefore these individuals will have a stake in the outcome, will feel ownership of the results and will become the authoritative spokespersons to their governments and citizens. In this way, a more accurate assessment of the full consequences of earthquakes will become credible, visible and inter-comparable between countries and cities."***

The SARA project has been successfully carried out with these ambitious goals always in mind. All work undertaken has been performed observing GEM's guiding principles of collaboration, credibility, transparency, and serving the public good, and the findings of this report testify to their achievement. The significant involvement of local scientists is detailed in the list of contributors and participants in the appendix.

The report is structured according to the process of assessing risk. It starts with an overview on the lasting impact of SARA and the lessons learned, which have already led to numerous follow-on activities driven by the local community. In Section Two the work on hazard components and hazard assessment is presented. Section Three examines risk, portraying its subcomponents of exposure, fragility/vulnerability and associated physical risk. For the first time, an open and uniform exposure model for the region has been developed, and combined with seismic hazard to estimate the potential for economic and human loss. These data and results are now publicly available and at disposal for city planners, civil protection authorities, local risk experts and

other practitioners. Through close bilateral collaborations and locally organized workshops and meetings, several experts in the region have developed city scenario analysis using transparent and identical approaches, thus allowing a direct comparison of the risk across the different urban centers in the region. This close collaboration with local institutions and experts resulted in outcomes going well beyond those originally planned. In Medellin, for example, the work done for the city was extended to cover the entire department of Antioquia, of which Medellin is the capital. These experiences are now being applied already to other cities of Colombia in locally led follow-up initiatives. In Quito, the collaboration with the Municipal government and the local universities permitted the individual survey of about 10,000 buildings, which completed, validated and significantly improved the quality of the exposure model prepared for the city to reach levels of accuracy not available before the project. Results of this project, based on a much better and complete understanding of the exposed assets and their risk, can be used to develop better-tailored risk transfer solutions.

But real risk is much more than physical risk: the preparedness and capacity of a community to withstand and recover from the impact of catastrophic events like earthquakes is an important element influencing their final impact. This element is described in Section Four, and has been addressed by defining indicators for social vulnerability (characteristics within social systems that create the potential for loss or harm) and resilience (the ability of systems to respond to and recover following perturbations from hazard events), and methodologies to define them. These indicators are then combined with physical risk, resulting in a holistic view of earthquake risk, called “Integrated Risk”. This has led to new insights on earthquake risk in countries of the region by providing new understanding on the actual vulnerability of a community. The same physical damage, say the collapse of a hospital, has very different impact in areas of the country with different levels of income, for example. While the collapsed hospital may be one of the several available in a wealthy area, it may be the only one in a low-income area of the same country. The impact of the same physical damage will clearly be very different in the two areas. This holistic view of risk is also very useful in understanding and quantifying the relative capacity of different areas in a country to return to normalcy in the shortest possible amount of time. These insights will certainly assist countries like Ecuador, where a detailed analysis of integrated risk for the entire country was completed, to assign priorities in ways that were not available previously. To be more effective, governments and stakeholders now have not only a better understanding of the physical components of earthquake risk, but also of the social characteristics that give rise to vulnerabilities within the communities they protect. The overall approach outlined in this report leads to a risk assessment that considers loss as part of a dynamic system, and our findings suggest that there are spatial differences in physical earthquake risk, social vulnerability, and integrated risk within the region. Earthquake mitigation and planning under these circumstances requires special attention where different aspects of social vulnerability affect the way in which communities will prepare for and respond to seismic threats. The latter was addressed via workshops that fostered the discovery of key areas of opportunity to reduce risk within social, economic, institutional, and infrastructural systems. The complete information produced in SARA is openly accessible on the SARA Wiki and the OpenQuake-platform.

As briefly documented in the financial overview in Appendix B, the budget has been fully expended, with a shift from salaries and workshops in favor of subcontracts with local collaborators as a more effective way to ensure the active involvement of local expertise. In this way the project succeeded in leveraging additional funds to the value of more than 550,000€ (as of January 2016) for locally driven follow-up activities in Colombia, Ecuador, Peru and Chile, with more anticipated as a result of the dissemination of this report.

Our sincere thanks go to the Swiss Re Foundation who have been the principal sponsor of the project, and contributed actively to its execution with not only funding, but also in providing conceptual, scientific and logistical support. We also thank all GEM sponsors for the use of their unrestricted funds for additional collaboration projects. But beyond financial support, SARA would not have been possible without the substantial technical and in-kind contributions of our local partners in government, academia and industry. We gratefully acknowledge the willingness and contributions of the whole GEM community to make the SARA project a success and a pilot case for application to other countries and regions in South America and around the world.

TABLE OF CONTENTS

APPENDIX A Earthquake Risk Country Profiles

The findings and results of the hazard, risk and social vulnerability analyses were integrated to produce Earthquake Risk Country Profiles. These Country Profiles present a quick but comprehensive view of a country's earthquake risk. The various metrics included in these profiles are summarized below:

1. **Social indicators:**
    - Population: Total amount of people living in the country, according to the respective National Statistical Office.
    - GDP: Annual gross domestic product, according to the World Bank database.
    - Capital stock: Economic value of the property of a given country, according to the World Bank database.
    - Life expectancy: Number of years that a person is expected to live (on average) based on the year of their birth, according to the United Nations database.
    - GINI Index: Is a statistical parameter intended to measure the income distribution of a nation's residents. A low GINI index indicates a balanced distribution of the income in a given country. This parameter was collected from the United Nations database.
    - Gross savings: Sum of the private and public savings, according to the World Bank database.

2. **Risk indicators:**
    - Population at risk: Amount of people exposed to a peak ground acceleration of 0.2 g, for a return period of 475 years.
    - Property at risk: Amount of economic value exposed to a peak ground acceleration of 0.2 g, for a return period of 475 years. Currently, this metric only includes the value of the residential building stock.
    - AAL - economic: Average annual economic losses calculated using a probabilistic event-based approach. Currently, this metric only considers losses from the residential building stock.
    - AAL - fatalities: Average annual human losses calculated using a probabilistic event-based approach.
    - Maximum economic loss: Highest economic loss from a single event calculated using a probabilistic event-based approach.
    - Probable maximum loss: Economic loss corresponding to a return period of 200 years.

3. **Financial indicators:** In this section an aggregated loss curve is presented, which establishes the relation between the aggregated losses (considering only the residential building stock) and a set of return periods (in years).

4. **High-risk regions:** List of the 15 regions (second administrative level) with the highest seismic risk, measured using the average annual economic loss.

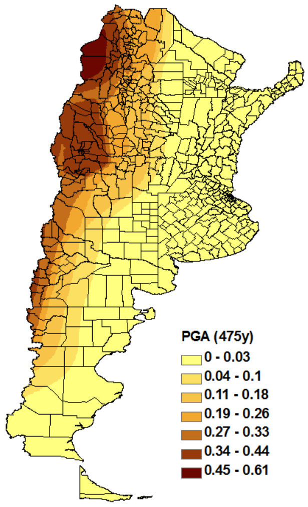
In addition, a brief description of important past events in each country is also provided. The information about the economic and human losses was extracted from EM-DAT (www.emdat.be).

This appendix includes the Earthquake Risk Profiles for Argentina, Bolivia, Chile, Colombia, Ecuador and Venezuela.

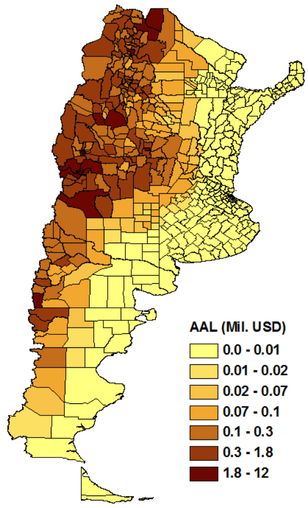
Earthquake Risk Profile for Argentina

The vast majority of the population and property of Argentina is located in the eastern part of the country, where the seismic hazard is particularly low. However, there are still a number of important settlements near the Andes, which have suffered considerable human and economic losses throughout time. The most relevant event occurred in the Province of San Juan in January 1944 causing more than 10,000 fatalities. In November 1977 a similar event happened in the same province causing approximately 80 million USD in economic losses.

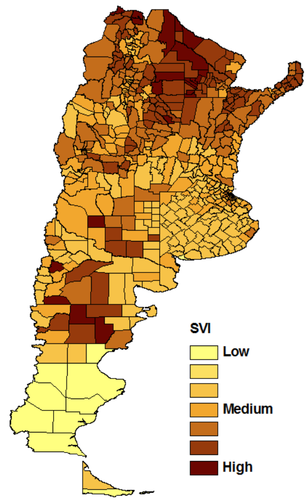
Seismic hazard



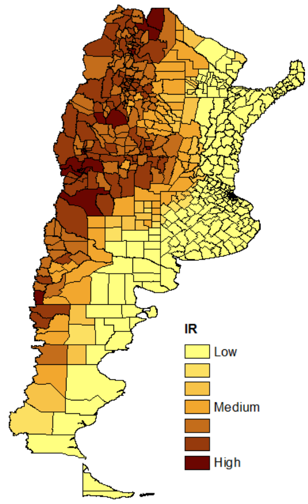
Seismic risk



Social vulnerability



Integrated risk



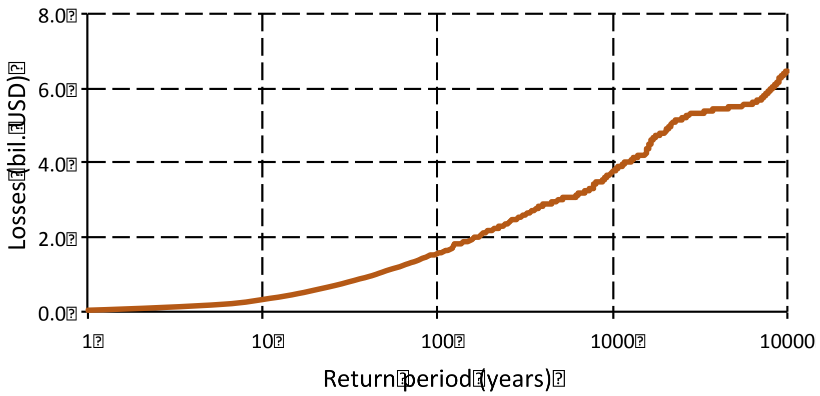
Social indicators

Population (mil.):	41.4
GDP (bil. USD):	612
Capital stock (bil. USD):	1381
Life expectancy:	76.0
GINI Index:	44.5
Gross savings (bil. USD):	101.6

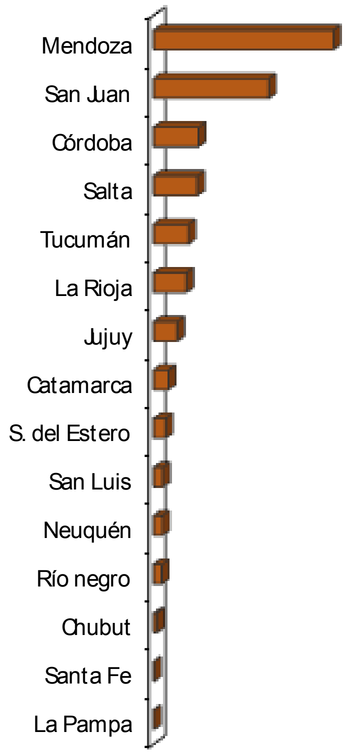
Risk indicators

Population at risk (mil.):	6.96
Property at risk (bil. USD):	81.1
AAL (economic – mil. USD):	155
AAL (fatalities):	8.6
Max. economic loss (bil. USD):	9.7
Probable max. loss (bil. USD):	2.1

Financial indicators



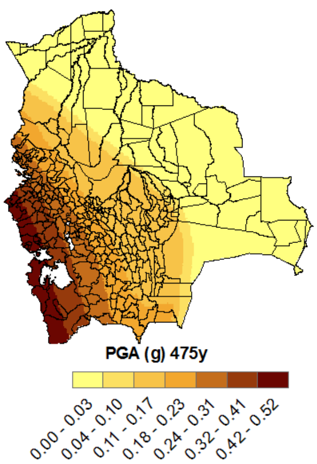
High risk regions

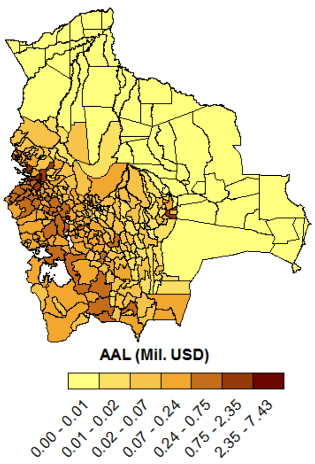


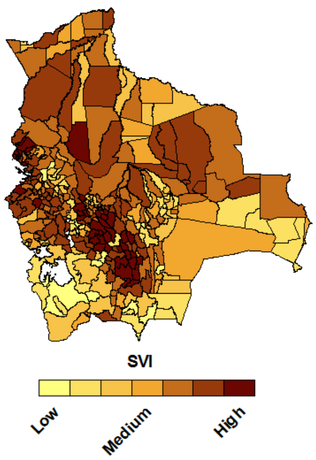
Earthquake Risk Profile for Bolivia

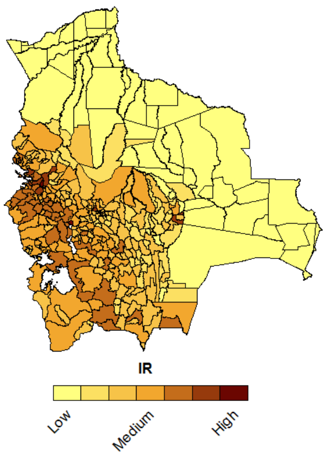
Despite the high seismic hazard in the western part of Bolivia, most of the population is located in the central part of the country, where the seismic hazard is significantly lower. The majority of the building stock is composed of non-engineered structures, which can be considerably vulnerable to earthquakes. In June 1994 a magnitude 8.4 (M_w) earthquake occurred at a depth of 650 km in the northwest part of the country causing five fatalities. In 1998, another event with a moderate magnitude (6.6 M_w) caused 95 fatalities and more than 5000 homeless.

Seismic hazard	Seismic risk	Social vulnerability	Integrated risk









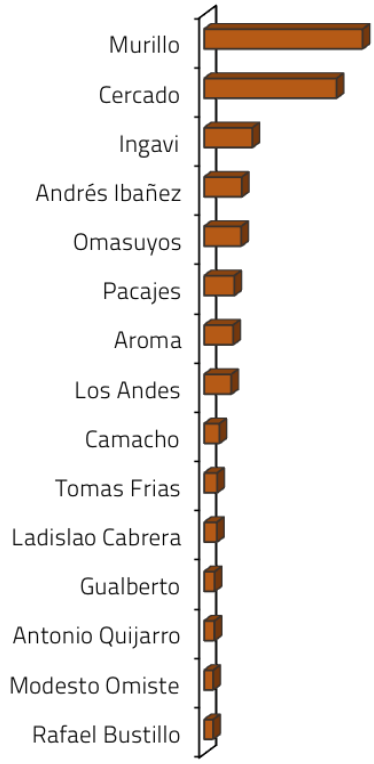
Social indicators

Population (mil.):	10.6
GDP (bil. USD):	30.6
Capital stock (bil. USD):	60.6
Life expectancy:	66.9
GINI Index:	56.3
Gross savings (bil. USD):	7.0

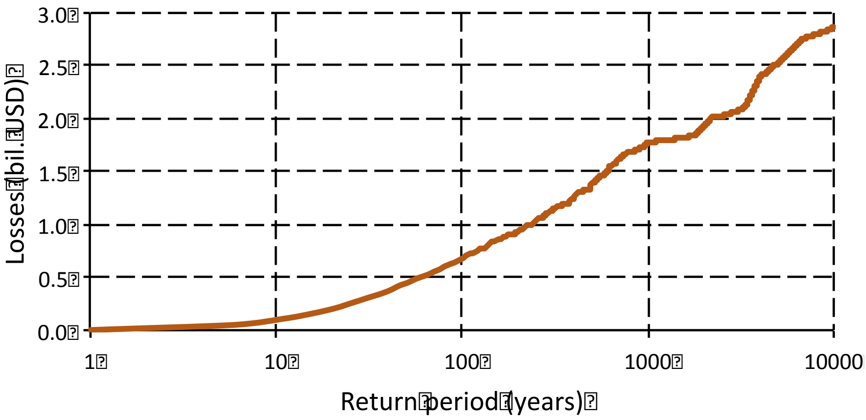
Risk indicators

Population at risk (mil.):	4.0
Property at risk (bil.USD):	10.1
AAL (economic – mil. USD):	47.9
AAL (fatalities):	7.1
Max. economic loss (bil. USD):	3.3
Probable max. loss (bil. USD):	0.9

High risk regions



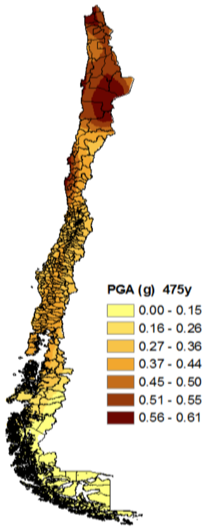
Financial indicators



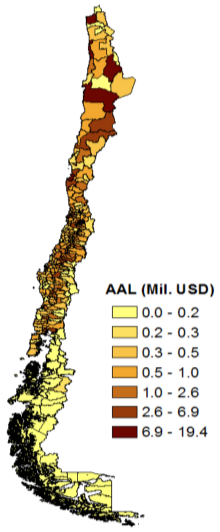
Earthquake Risk Profile for Chile

Chile is a country with one of the world's highest seismic activity. In May 1960, the strongest earthquake ever recorded (M_w 9.5) occurred near the city of Valdivia. Between the period of 2000 and 2015, six major earthquakes have occurred, causing a total economic loss of approximately 30 billion USD. The Maule earthquake of February 2010 (Mw 8.8) alone caused a loss toll of approximately 5% of the annual gross domestic product of Chile, and more than 500 fatalities.

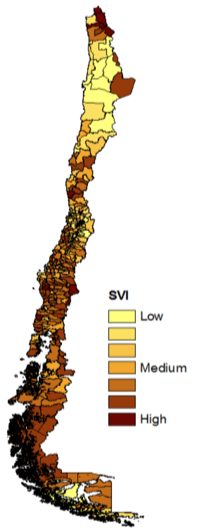
Seismic hazard



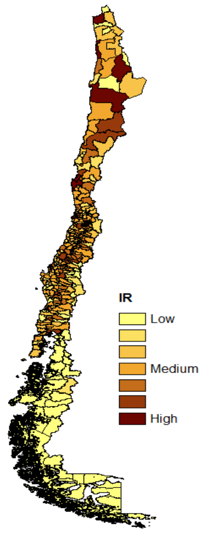
Seismic risk



Social vulnerability



Integrated risk



Social indicators

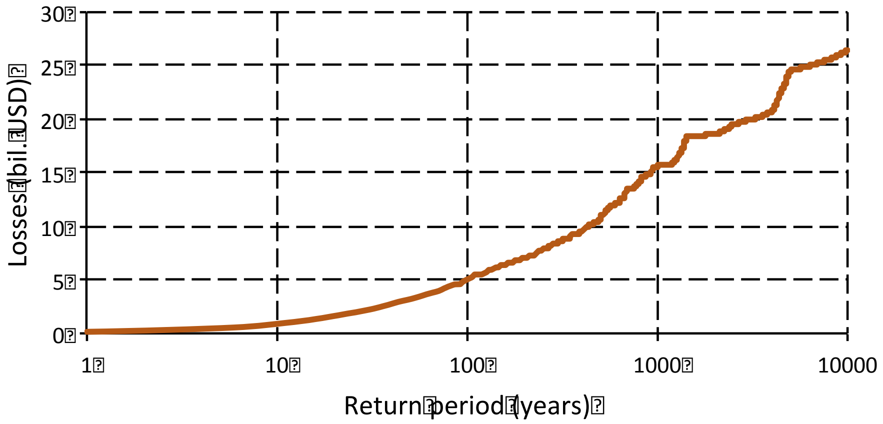
Population (mil.):	17.6
GDP (bil. USD):	277.2
Capital stock (bil. USD):	784.1
Life expectancy:	79.6
GINI Index:	52.1
Gross savings (bil. USD):	57.6

Risk indicators

Population at risk (mil.):	15.0
Property at risk (bil. USD):	236.5
AAL (economic – mil.USD):	487.6
AAL (fatalities):	23.9
Max. economic loss (bil. USD):	28.2
Probable max. loss (bil. USD):	7.1

High risk regions

Financial indicators

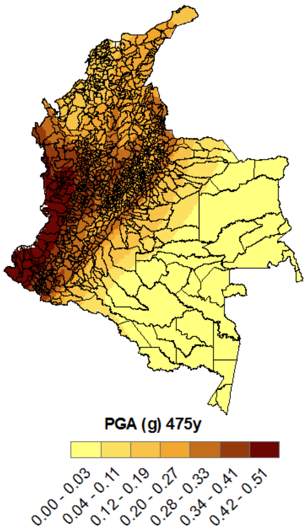


Earthquake Risk Profile for Colombia

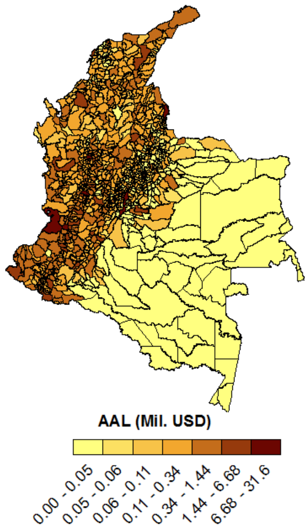
GEM
GLOBAL EARTHQUAKE MODEL
working together to assess risk

In terms of population and property, Colombia has one of South America's highest exposure levels to significant seismic hazard. In the last century, earthquakes have caused more than 3,000 fatalities and economic losses of approximately 2.3 billion USD. The Armenia earthquake (M_w 6.2) of January 1999 caused more than a 1000 fatalities and an economic loss of almost 2% of the annual gross domestic product of Colombia. The wide spread damage was mostly due to the existence of non-engineered building and informal construction.

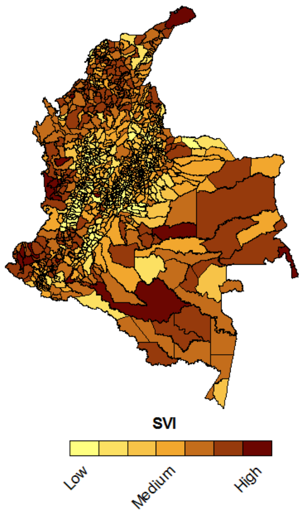
Seismic hazard



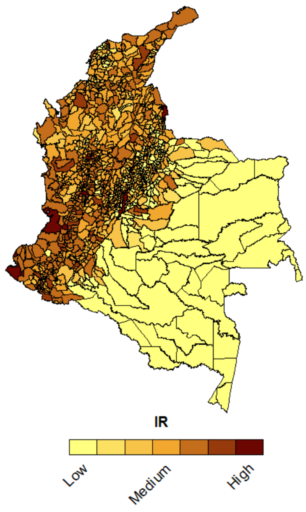
Seismic risk



Social vulnerability



Integrated risk



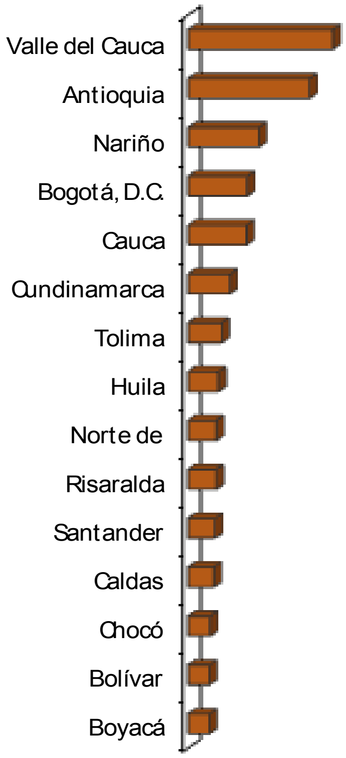
Social indicators

Population (mil.):	48.3
GDP (bil. USD):	378.1
Capital stock (bil. USD):	944.6
Life expectancy:	73.8
GINI Index:	55.9
Gross savings (bil. USD):	72.0

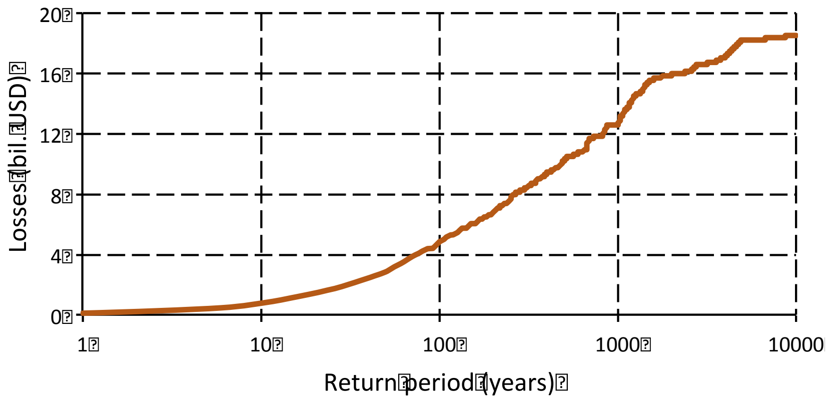
Risk indicators

Population at risk (mil.):	32.8
Property at risk (bil. USD):	255.1
AAL (economic – mil. USD):	430.4
AAL (fatalities):	31.8
Max. economic loss (bil. USD):	25.2
Probable max. loss (bil. USD):	6.7

High risk regions



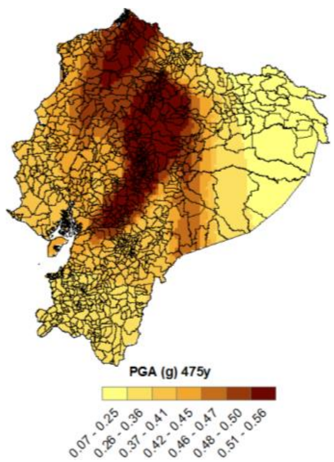
Financial indicators



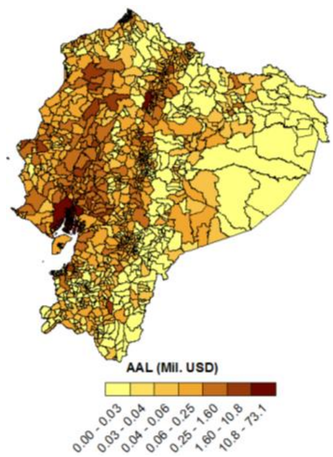
Earthquake Risk Profile for Ecuador

Almost one third of the population of Ecuador is concentrated in two cities (Guayaquil and Quito), which unfortunately are located within regions of moderate to high seismic hazard. In the last century, several strong earthquakes have cause more than 10,000 fatalities, and an economic loss of approximately 2 billion USD. In particular, the earthquake sequence of March 1947 involved three events of magnitude above M_w 6.0 located in the Northern part of the country, and macroseismic intensities of IX were registered.

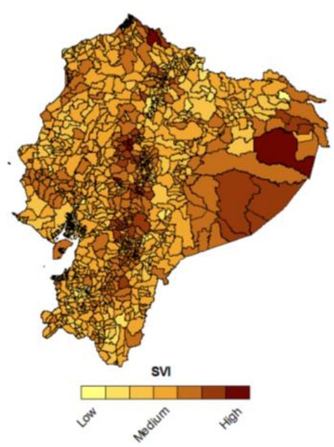
Seismic hazard



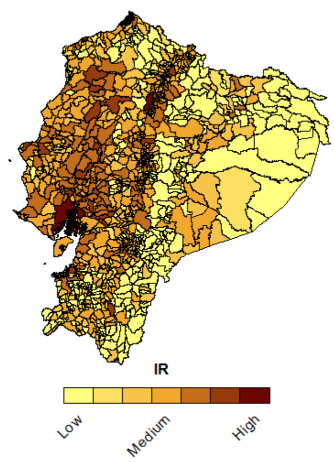
Seismic risk



Social vulnerability

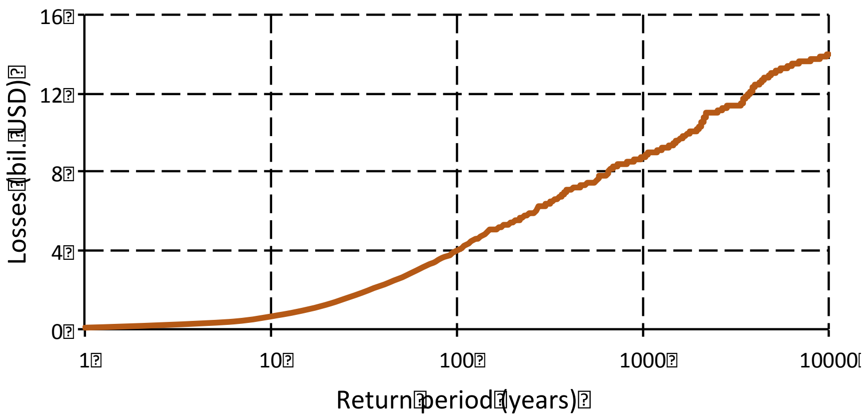


Integrated risk

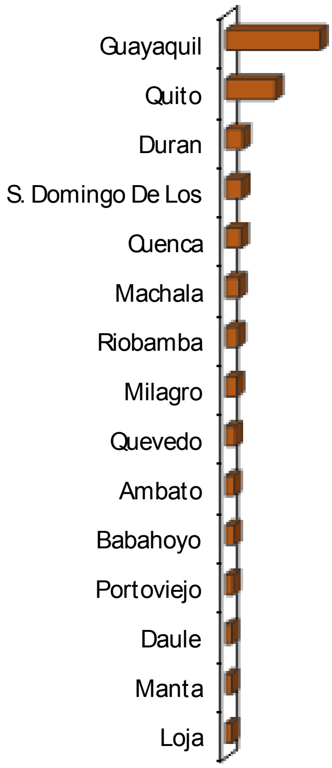


Social indicators		Risk indicators	
Population (mil.):	15.7	Population at risk (mil.):	14.4
GDP (bil. USD):	90.0	Property at risk (bil. USD):	75.0
Capital stock (bil. USD):	282.7	AAL (economic – mil. USD):	344.3
Life expectancy:	76.2	AAL (fatalities):	32.0
GINI Index:	49.3	Max. economic loss (bil. USD):	14.1
Gross savings (bil. USD):	24.1	Probable max. loss (bil. USD):	5.5

Financial indicators



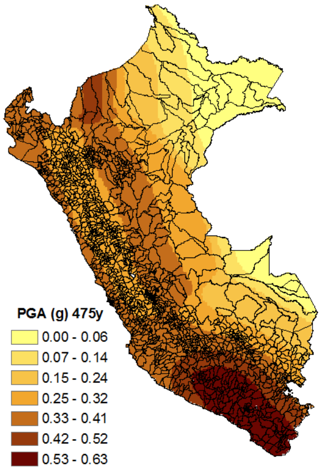
High risk regions



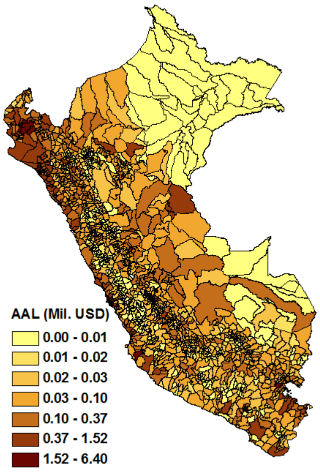
Earthquake Risk Profile for Peru

The seismic event with the highest death toll in the Peruvian territory occurred in May of 1970. This earthquake of M_w 7.9was followed by a large landslide, causing more than 65,000 fatalities. More recently, an earthquake of M_w 8.0 struck the region of Pisco causing 593 fatalities and an economic losses exceeding 1 billion USD. Peru has a high percentage of unreinforced masonry and adobe construction, which has a poor seismic performance even for seismic events of low to moderate magnitude.

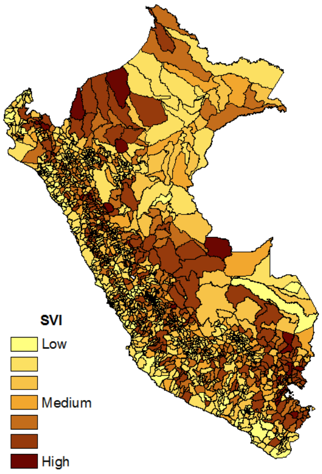
Seismic hazard



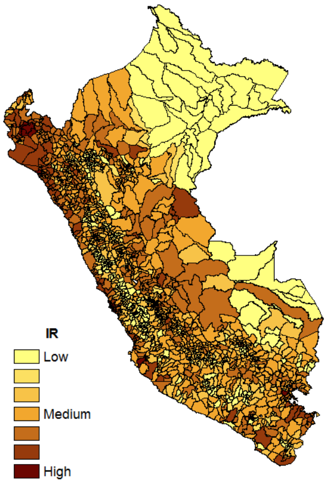
Seismic risk



Social vulnerability



Integrated risk



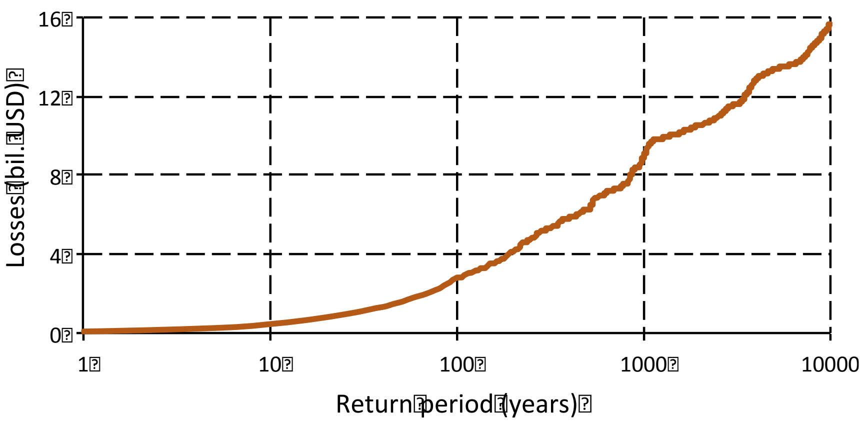
Social indicators

Population (mil.):	30.4
GDP (bil. USD):	202.3
Capital stock (bil. USD):	692.3
Life expectancy:	74.5
GINI Index:	48.1
Gross savings (bil. USD):	45.2

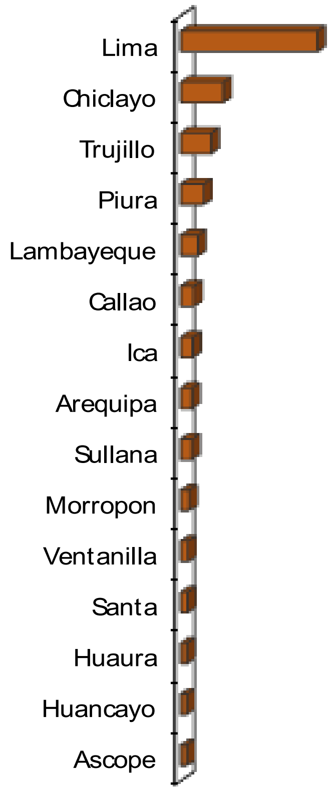
Risk indicators

Population at risk (mil.):	21.9
Property at risk (bil. USD):	92.2
AAL (economic – mil. USD):	273.5
AAL (fatalities):	29.3
Max. economic loss (bil. USD):	20.2
Probable max. loss (bil. USD):	4.2

Financial indicators



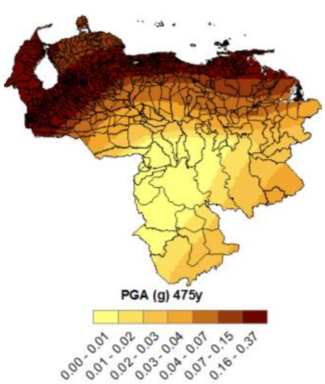
High risk regions



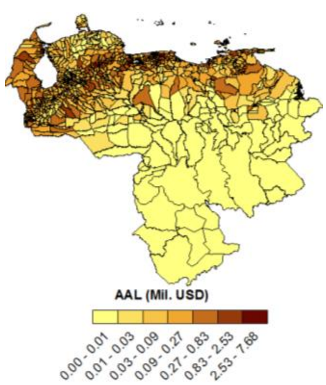
Earthquake Risk Profile for Venezuela

In the last century, five major earthquakes have struck the Northern region of Venezuela, causing more than 400 fatalities and leaving thousands homeless. The most recent, significant event occurred in July 1967 (M_w 6.6) near the capital, Caracas, causing 240 casualties and approximately 90 million USD in property damage. The main causes for the extensive damage observed in past events (despite the moderate magnitude) is the high concentration of population and property in seismic hazard prone areas, and the prevalence of non-engineered construction

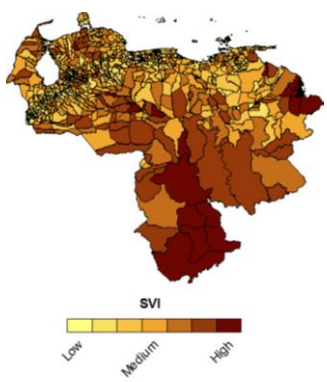
Seismic hazard



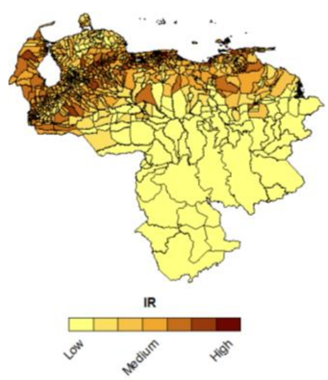
Seismic risk



Social vulnerability



Integrated risk



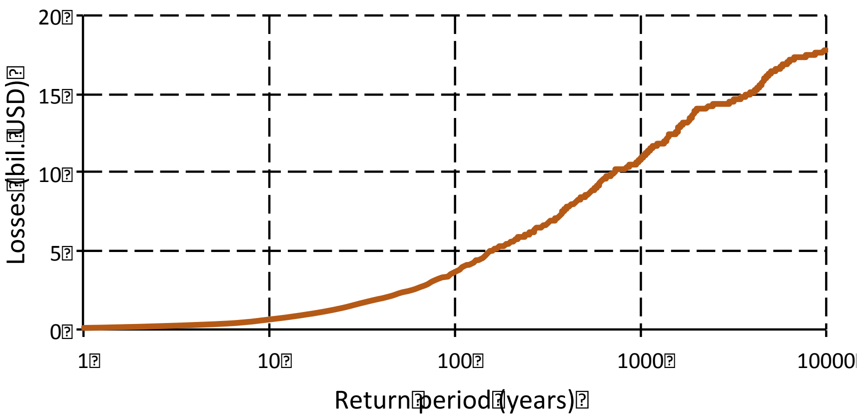
Social indicators

Population (mil.):	30.4
GDP (bil. USD):	438.3
Capital stock (bil. USD):	1155
Life expectancy:	74.5
GINI Index:	44.8
Gross savings (bil. USD):	97.8

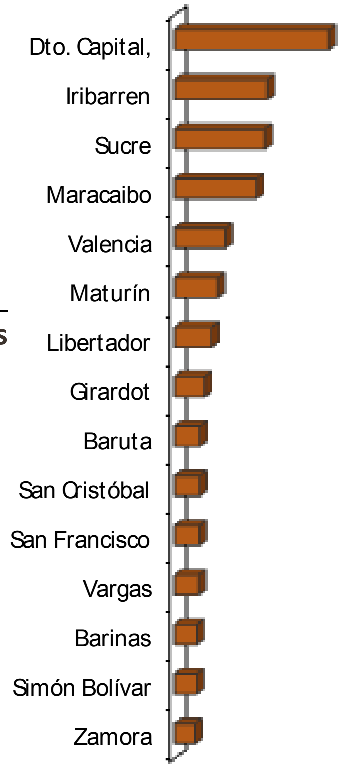
Risk indicators

Population at risk (mil.):	16.0
Property at risk (bil. USD):	108.3
AAL (economic – mil. USD):	326.2
AAL (fatalities):	21.0
Max. economic loss (bil. USD):	19.8
Probable max. loss (bil. USD):	5.5

Financial indicators



High risk regions



APPENDIX C List of participants and contributors

Hazard Component

Current state of practice

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Hugo Yepes – Instituto Geofísico/EPN, Ecuador

Modeling subduction zones

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Strong motion database and GMPEs

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Database of crustal faults

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Irene Perez - Instituto Nacional de Prevención Sísmica, Argentina
Isabel Santibanez - Universidad Católica de Chile, Chile

New PSHA input model

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Graeme Weatherill – Senior Hazards Scientist

Earthquake catalogue – Pre 1960

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Earthquake catalogue – Post 1960

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Risk Component & Socioeconomic Vulnerabilities and Integrated Risk Component

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Jair Torres – UNESCO, Paris

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Jairo Valcárcel – External collaborator, SARA Project

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Anirudh Rao – Physical Risk Engineer
Chiara Casotto – PhD Student
Mabe Villar – MSc Student

Socioeconomic vulnerability and resilience

Miguel Toquica – Social Vulnerability Scientist

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Paul Henshaw – Director of Technology & Development
Rui Pinho – Secretary General (2009 – 2013)
Helen Crowley – Deputy Secretary General (2009 – 2014)

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