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TREQ Project

Executive summary
Urban seismic risk assessment for the cities of Quito, Cali and Santiago de los Caballeros

Deliverable 2.3.5 – Version 1.1.0

Global Earthquake Model (GEM) Foundation

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Executive summary report for the urban seismic risk assessment for the cities of Quito, Cali and Santiago de los Caballeros

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Urban seismic risk assessment for the cities of Quito, Cali and Santiago de los Caballeros

Deliverable D2.3.5

Technical report produced in the context of the TREQ project

Version 1.1.0 – June, 2022

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Global Earthquake Model Foundation

Global Earthquake Model

Collaborators

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The TREQ Project is designed to demonstrate how earthquake hazard and risk assessment can inform decision makers in the development of risk reduction policies, as well as how earthquake risk can be properly communicated to stakeholders and the public in general. Specifically, the project aims to develop capacity for urban earthquake risk assessment in Latin America, Quito (Ecuador), Cali (Colombia), and Santiago de los Caballeros (Dominican Republic), while the second part will produce training, educational and communication materials that will enhance the understanding of earthquake risk worldwide. This program targets a wide spectrum of stakeholders, categorized into four main groups: governance (decision-makers/public authorities), industry (practitioners and professionals), academia (researchers and professors), and the community.

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This seismic risk component at urban level covers the development of uniform, open and transparent datasets for the urban building inventory (exposure model), the physical response of the infrastructure under seismic loads (vulnerability model), and the assessment of the impact from earthquakes, along with risk metrics required for the development of risk reduction plans.

Earthquake loss assessment models have been developed in close collaboration with technical groups in each of the selected cities: Quito (Ecuador), Cali (Colombia), and Santiago de los Caballeros (Dominican Republic. Researchers, city officials and risk managers actively participated in the different model component of the present study, such as data collection, development of the exposure database and discussion of vulnerability functions appropriate for the construction practice. Urban risk assessment results and selection of earthquake scenarios are key components of the study to support the cities risk management offices to improve earthquake risk awareness, preparedness and emergency response strategies. This document provides an executive summary of the data, methodologies, and main outcomes of the urban risk component. Accompanying reports for the urban seismic hazard assessment, definition of building classes and databases required for the analysis are available in other TREQ deliverables.

The urban risk assessment in the TREQ cities shows the importance of hazard, site response, exposure and vulnerability models that capture the details and dynamics of the city. These input models are fundamental for the identification of the main drivers of risk in Quito, Cali and Santiago de los Caballeros. Local site characterization can exacerbate (e.g. in Quito) or reduce (e.g. Cali) the seismic risk estimates when combined with the different building classes present in the different seismic zones of the cities. Furthermore, local models reduce the uncertainty associated with the use of low-resolution proxy datasets and other assumptions commonly present in national and regional scale models. Sensitivity analysis indicated that the quantification of the impact, in terms of the expected economic losses, human fatalities or the number of collapsed buildings at different return periods, can be modified by one or more orders of magnitude. The resulting risk metrics are conditioned to the quality and accuracy of the input models, and therefore it is essential to adequately characterize the seismic hazard, the local soil response, the building inventory and its occupants, and the likely response of the structures under seismic action. Quito is an example of this. It is clear that the use of site response models based on regional scale proxy datasets results in an underestimation of seismic risk in more than 80% of the exposed assets and occupants in the city. In contrast, detailed information about the soil and exposed assets in Cali helped to better identify zones of lower risk. The deamplification of ground shaking intensity in areas with predominant mid-rise and high-rise construction resulted in better estimates of economic and human loss statistics in neighbourhoods that concentrate most of the economic value of the city. Using this information, more accurate city risk profiles have been produced for the risk management offices, which can later be used to inform risk management policies.

Each section of this executive summary provides the key products and findings regarding each component of the urban seismic risk models. To provide more context for the reader the dedicated report of each component is referenced as well. Documentation complementary to this summary can also be found on the TREQ project website (https://www.globalquakemodel.org/proj/treq).

Finally, to facilitate the transfer of the knowledge acquired by the parties involved, we have created an open access online repository at this link: https://github.com/gem/treq-riesgo-urbano. This repository contains all the information on the risk model developed together with each city's technical group and the results that we present in this report. We have also made available videos showing how to access and navigate the information produced by the project on the YouTube platform: https://youtu.be/FckyM5mZP10 and https://youtu.be/Bvj3VPFhQuc.

2 INTRODUCTION

Quito, Cali and Santiago de los Caballeros are cities located in high seismic hazard zones, aligned to the hazard zonation levels in the respective building code regulations. The three cities have experienced ground shaking in the past that compromised the life safety of their inhabitants and the stability of their infrastructure. Nowadays, each city has a land use and development plan (POT – Plan de Ordenamiento Territorial, in Spanish) in which there is a mandate to improve the understanding of natural hazards and their associated risks, as well as to reduce and mitigate the effects of natural hazards. The following paragraphs present an overview of the cities and provide key features that should be consider when analysing the results from the seismic risk assessment.

The city of Quito, which currently encompasses the municipalities of the Quito Metropolitan District or DMQ, is the capital of Ecuador and the political-administrative centre of the country. It currently houses more than 15% of the national population and 87% of the population of Pichincha, making it the most important urban centre in the province. It is also the fastest-growing city in the country. According to the Institute of Statistics and Censuses of Ecuador (INEC) the DMQ went from having a total population of 1.82 million inhabitants in 2001 to more than 2.23 million in 2010 (INEC, 2010). Today the inhabitants are distributed with 1.6 million people (72%) in urban areas and 630 thousand (24%) in rural areas. It is divided into zonal administrations that contain 66 parishes and more than 1200 neighbourhoods. Between the years 1760 and 1971, the greatest urban expansion occurred in the zonal administrations known today as the consolidated city (Gómez and Cuvi, 2016). However, from the 1970s onwards, the parishes with the highest population growth were found in the urban periphery and suburban areas. For example, in 2010 the Manuela Saenz zonal administration, where the Historic Centre parish is located, reported an annual population decrease of 0.5%. On the other hand, the administrations with the highest growth occurred in the suburban area, as is the case of Calderón and Tumbaco with population increases of 4.7% and 3.0% per year respectively (POT Quito, 2011).

Cali is the most important city in southwestern Colombia. It is the largest urban centre connected to the port of Buenaventura on the Pacific coast and the industrial production centre of Yumbo. It currently houses about 5% of the national population, half of the population of the Valle del Cauca department and one of the fastest growing economies in the country. According to official statistics (DANE 2018, Cali en Cifras 2020), Cali went from having 2.11 million inhabitants in 1999 to 2.46 million in 2020. Of these, 2.45 million (98%) are within the urban perimeter of the city, distributed in 22 administrative divisions called Communes and 335 neighbourhood units. In rural areas, there are 36.6 thousand inhabitants in 15 administrative divisions called Corregimientos and 84 villages. At the same time, it is the largest city in Colombia located in an area of high seismicity, according to the classification of the territory by the NSR-10 seismic regulations. Since 1566 there have been more than 20 earthquakes that caused significant damage to the city. Among the most relevant in its modern history are the Manizales (Mw 7.2) and Tumaco (Mw 8.1) earthquakes of 1979 that caused more than 450 deaths on the Pacific coast, as well as the Popayán earthquake of 1983 (Mw 5.7) that caused more of 400 million USD in losses in Valle del Cauca department and almost 1% loss of the country's GDP (Días 1999).

The city of Santiago de los Caballeros has a great patrimonial and economic value for the Cibao Norte region of the Dominican Republic, being one of the largest industrial centres in the Caribbean. Being the third largest city in the country, it is estimated that its contribution to the Dominican GDP is between 15% and 18% (IDB 2015), concentrating one of the main sources of employment and the supply of educational and health services in the Republic. Dominican. It is also one of the regions with the highest population growth rate in the country. In 2002, the municipality of Santiago concentrated 553 thousand inhabitants, about 6.2% of the national population (ONE 2002). Currently, 750 thousand people live in the municipality of Santiago, more than 6.8% of the population of the Dominican Republic and an increase of more than 30% compared to the previous decade (ONE 2020). Santiago is administered in 6 municipal districts: Santiago (Cabecera), Pedro García, Baitoa, La Canela, San Francisco de Jacagua and Hato del Yaque. More than 82% of the municipal population lives within the urban limit of the city.

3 Seismic hazard at an urban scale

For the estimation of seismic risk at an urban scale it is necessary to have probabilistic seismic hazard models. The most recent seismic hazard models available at national level for Colombia and Ecuador. In the case of Quito, the authors of the latest hazard model developed for Ecuador (Beauval et al. 2018) provided an updated PSHA model branch specifically for TREQ activities. For Cali we used the national PSHA model developed the Colombian Geological Survey (SGC) (Arcila et al. 2020). For the Dominican Republic, a national probabilistic hazard model was developed, in collaboration with the National Geological Survey (SGN) and the Autonomous University (UASD). The selected national models were used for the definition of the reference ground motion hazard on bedrock for the three selected cities, and for the selection of possible earthquake scenarios to be used for risk analysis. At a local scale, the information required for completing an urban seismic hazard assessment was collected, and improved the estimates of ground shaking hazard using more refined information and more specific methodologies. The table below summarizes the activities and deliverables completed.

For additional information the reader is referred to the following technical reports:

- D2.2.1 Description of the compiled datasets and the selected seismic hazard models
- D2.2.2 National earthquake hazard model for the Dominican Republic
- D2.2.3 Seismic hazard results (rock and soil conditions)
- D2.2.4 Seismic hazard analysis at the urban scale

The following section briefly discussion of seismic hazard within the context of the urban risk assessment for the cities.

3.1 Seismic hazard and site response models

Using the OpenQuake engine classical PSHA calculator (Pagani etl al. 2014) the peak ground acceleration (PGA) with 10% probability of exceedance in 50 years was estimated for the cities. The results are presented on the three maps in Figure 1. These intensities are shown on bedrock using a reference Vs30 value of 800 m/s. Of the three cities Cali exhibits the lowest level of seismic hazard, with the PGA values ranging from 0.35g to 0.40g very constant through the valley. The PSHA results for Quito suggest higher hazard values for the same probability of exceedance, ranging from 0.45g to 0.55g, with the highest ranges found on areas of great population density. Santiago is the city with the highest seismic hazard, ranging from 0.35g up to 0.70g in populated areas. The expected intensity increases towards the northeast of the city, where the Septentrional Fault crosses the north Cibao valley.

The estimation of seismic hazard on rock provides a reference value of hazard for the cities. However, earthquake loss assessment models need to consider amplification of ground shaking intensity due to site conditions for reliable assessment of risk metrics (Silva, 2017). This can be done using datasets of proxy shear wave velocity values for the soil measured at 30 meters depth (Vs30) (Wald and Allen, 2007). Proxys are used when there is no information pertaining the geotechnical properties of the soil. Besides making use of the vs30 proxy datasets, soil response models were developed for each city using information from previous studies on seismic microzonation and geotechnical surveys in order to improve the characterization of the soil response.

The site response models estimate of the ground shaking intensity at the bedrock and amplify it using a scalar factor to better represent the level of intensity at the surface. This factor is a function of the geotechnical properties of the soil, the intensity measure type, the level of ground shaking intensity and the aleatory uncertainty associated to the ground motion model (GMPE). Therefore, it allows to make estimates of structural response amplification for a wide range of structures and seismic events using a probabilistic approach. The deliverable "*D2.2.4 Seismic hazard analysis at the urban scale*" presents the amplification function (AF) developed for each seismic zone per city: Quito with 13 zones, Cali with 10 zones and Santiago with 10 zones. These zones cover the urban extent of the city boundaries. **Figure 2** presents the example of amplification functions in two zones of Quito.

The present study considers three different site conditions for the estimation of seismic risk:

1. Intensities estimated at bedrock (as reference value)
2. Intensities estimated at the surface using the vs30 proxy datasets
3. Intensities estimated at the surface using the amplification function developed for each microzone.

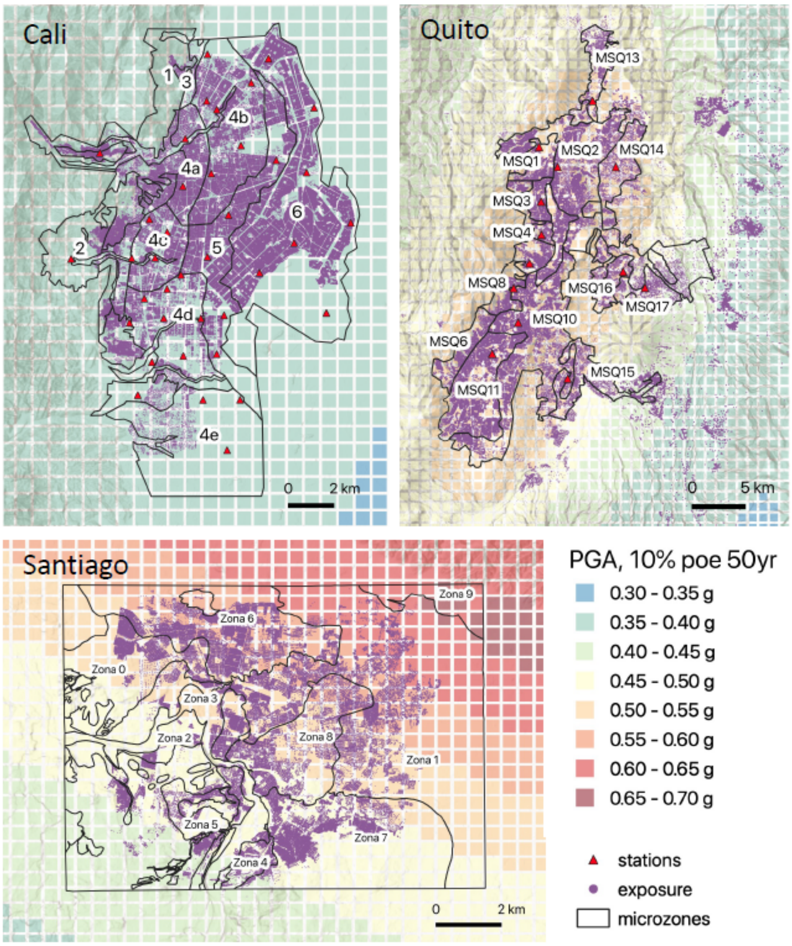


Figure 1. Seismic hazard maps for PGA with a 10% probability of exceedance in 50 years for Quito, Cali and Santiago de los Caballeros, featuring the seismic microzones of each city in the background.

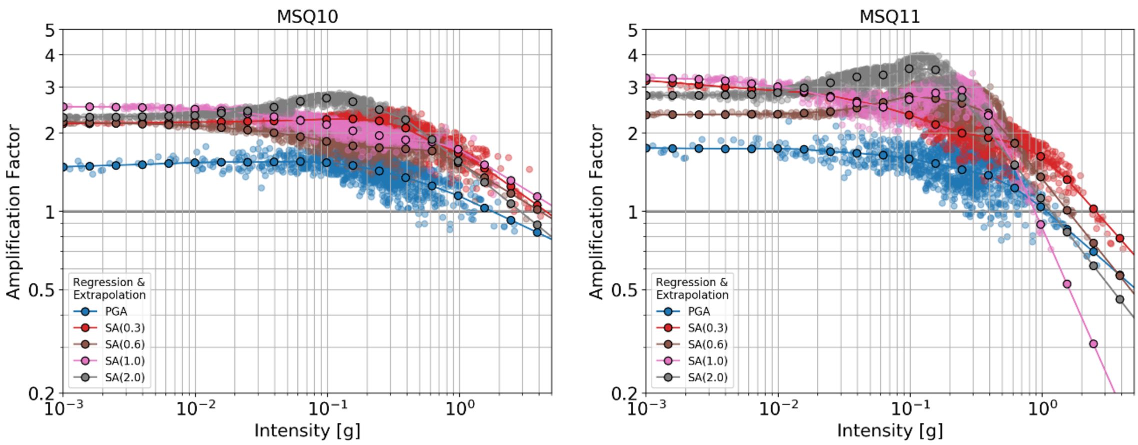


Figure 2. Two amplification functions (AF) for Quito microzones MSQ10 and MSQ11, featuring the value of the amplification factor for a wide range of ground shaking intensities and four intensity measure types.

4 EXPOSURE DATABASES

An exposure model is fundamental for the assessment of the impact due to natural hazards, as it comprises information concerning the geographical location, vulnerability characteristics and value of the assets exposed to the hazards. The man-made environment, its contents and occupants are all elements exposed to natural hazards and must be examined to correctly quantify their physical vulnerability and potential risk (GFDRR 2014). The GEM Foundation has developed exposure datasets for Ecuador, Colombia and the Dominican Republic as part of the Global Risk Model activities in 2018 (Silva et al. 2020). As part of the TREQ activities, the exposure information available for each city was improved in order to provide detailed models suitable for earthquake risk assessment at the urban scale. Among the main improvements to the datasets, we highlight the detailed spatial resolution of the assets, the robust characterization of the buildings, including all occupancy categories, and the updates regarding replacement cost. For Quito, Cali and Santiago this was achieved through the collection of better information for the cities and the constant involvement of the local experts in each one of development stages.

The resulting exposure databases are available in the deliverable *"D2.3.2 Geo-referenced exposure databases of buildings and population in the TREQ cities"*.

4.1 Data collection

The three cities have reach information about the structures in publicly official databases. A great amount of existing information was reviewed for each city, ranging from urban planning documents, administrative boundaries, city census, on-site surveys and cadastre databases. The information was collected through online enquiries in the city databases or directly from the local offices of risk management. In the three cities, it was possible to obtain updated high-resolution datasets on structures, the construction characteristics, the occupants and socio-economic indicators that allow an adequate characterization of the physical and social vulnerability of the city's assets and inhabitants. For Quito, a total of 29 datasets were used to define the exposure model. These include the official census of population and households (projected to 2020), the city cadastral database (2020), the land-use dataset (2016) and the historical development of the city squares from 1760 to 2015. For Cali, the latest cadastral database and city census were considered, as well as previous exposure models available for the city. From previous studies over 30 thousand building surveys were also collected and processed for modelling exposure. For Santiago de los Caballeros over 10 different datasets were collected, including the baseline dataset of land use of the city that features the economic purpose of the land per city lot. Additional datasets were gathered containing the age of the city, predominant construction material and the average number of stories per city block. From these sources all the information required to model exposure was obtained. As an example, **Figure 3** presents a set of maps derived for Cali, using building attributes included in the model.

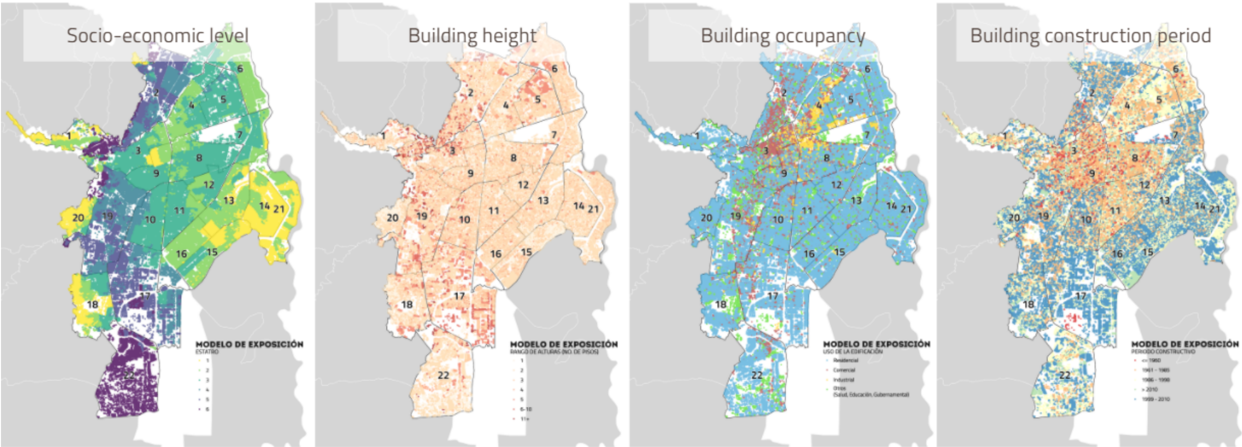


Figure 3. Different building attributes derived from the categorical variables in the datasets collected for the city of Cali.

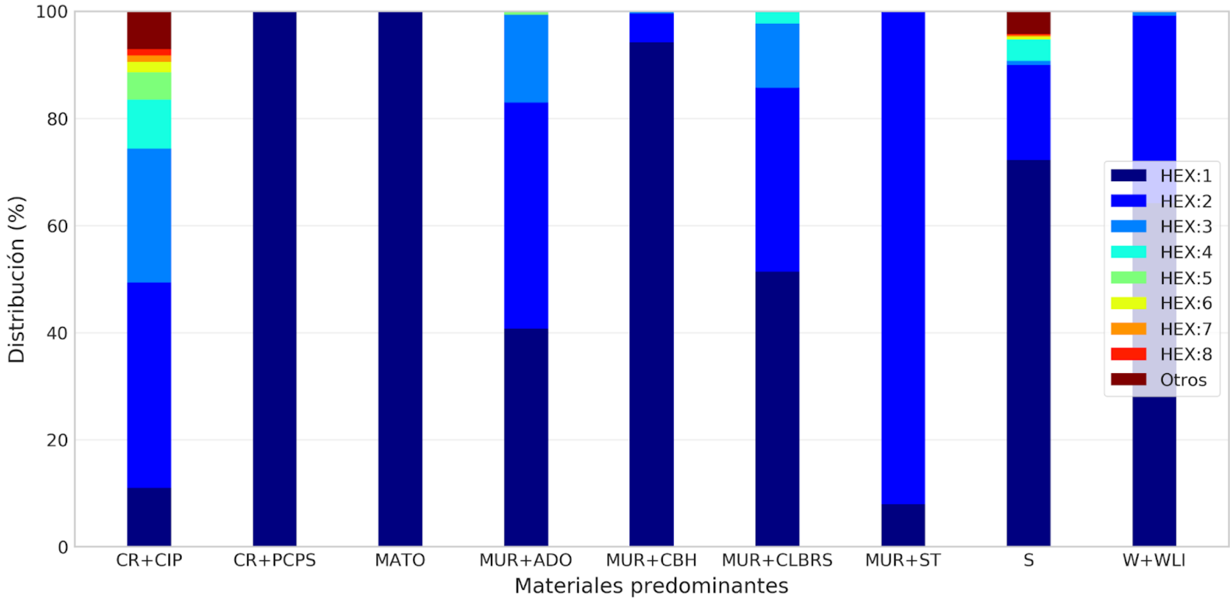
4.2 Building classification

The first step in developing an exposure model is the definition of classes that allow the grouping of buildings with similar characteristics. Since the use of the model is for urban risk assessment, the classification tried to preserve all physical characteristics that might influence the expected performance of buildings under different hazard. For example, the model includes information regarding the material and type of the lateral load resisting system, number of storeys, ductility level, and occupancy class. The proposed classification follows the GEM Taxonomy (Brzev et al, 2013).

To assess urban seismic risk, it was necessary to identify the most predominant building typologies in each city and the most suitable models to account for their seismic fragility and vulnerability. The identification of the main building classes for each city has been thoroughly documented in the deliverable "*D2.3.1 - Description of building classes identified in the TREQ cities".* Herein a main summary of the findings of the exposure modelling process is provided for context.

4.2.1 Quito

Masonry is the most widely used building material in Quito. The latest population and housing census of Ecuador estimated that in 2010 more than 75% of the houses in Quito have masonry blocks as the material for the exterior walls (INEC, 2010). **Figure 4** presents the distribution of the exposed economic value in Quito among the main construction materials and administrative zones. Masonry is found throughout the city, for various occupancy types and in different configurations. Its most common configuration is confined by concrete frames (CR+CIP/LFINF) of one, two and three storeys (HEX:1, HEX:2, HEX:3), which is dominant in all parts of the city. Unconfined masonry can be found in variants of clay brick (MUR+CLBRS), concrete bricks (MUR+CBH), adobe bricks (MUR+ADO), and to a lesser extent as stone bricks (MUR+ST). These configurations can range from one to four storeys. The bottom panel of **Figure 4** indicates that unreinforced masonry holds a significant portion of the exposed economic value, especially in the administrative zone of Centro Histórico and Norcentral. Reinforced concrete frames or dual systems (CR+CIP/LFM and CR+CIP/LWAL, respectively) are also widely used, mostly in formal and high-rise constructions (over 5 storeys) such as apartments or commercial buildings. Steel (S) is found through the city. It is used minorly for high-rise constructions over 8 storeys, and mainly in single-storey industrial warehouses. Wood and natural fibber (grouped into the W class) and waste materials (MATO) play a minor role in the urban construction but are commonly found in the rural areas like Noroccidente and almost entirely one or two storeys.



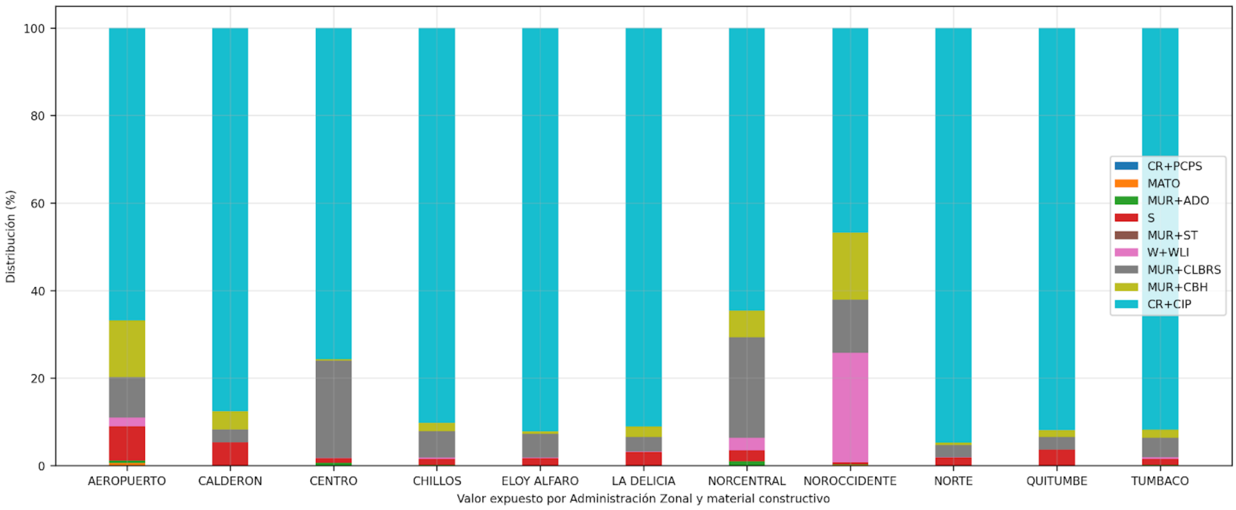


Figure 4. (Top) Distribution of exposed economic value in Quito, by building material and height configurations. (Bottom) Distribution of exposed economic value in Quito per administrative zone.

4.2.2 Cali

Masonry also has a predominant role in construction in Cali. For example, of the 4,937 buildings surveyed in previous studies (e.g., OSSO, 2017), about 65% correspond to masonry variants of concrete blocks reinforced (MR) or confined (MCF). Almost 25% correspond to highly vulnerable informal systems such as semi-confined (CR/LFINF), unreinforced (MUR) or adobe block masonry (MUR+ADO). Reinforced concrete (CR) records about 6% of the sample, widely used in apartment buildings, although cases of independent precast houses were also recorded. Wood (W) and other materials (MATO) are seldomly used within the urban area. In the TREQ project, three local experts contributed by providing mapping schemes for the classification of all the structures found in the city databases. According to their classification, the distribution of the whole population is agreement with those surveys. The top panel of **Figure 5** provides the exposed economic value distributed among the main building materials of the city according to each expert. Differences arise with regards to how experts classify the structures according to their expected vulnerability. In general, they suggest that slightly more structures should have some level of seismic provisions (larger portions of buildings with DUM and DUH taxonomy codes) in comparison with what on-site surveys suggest (DNO or DUL).

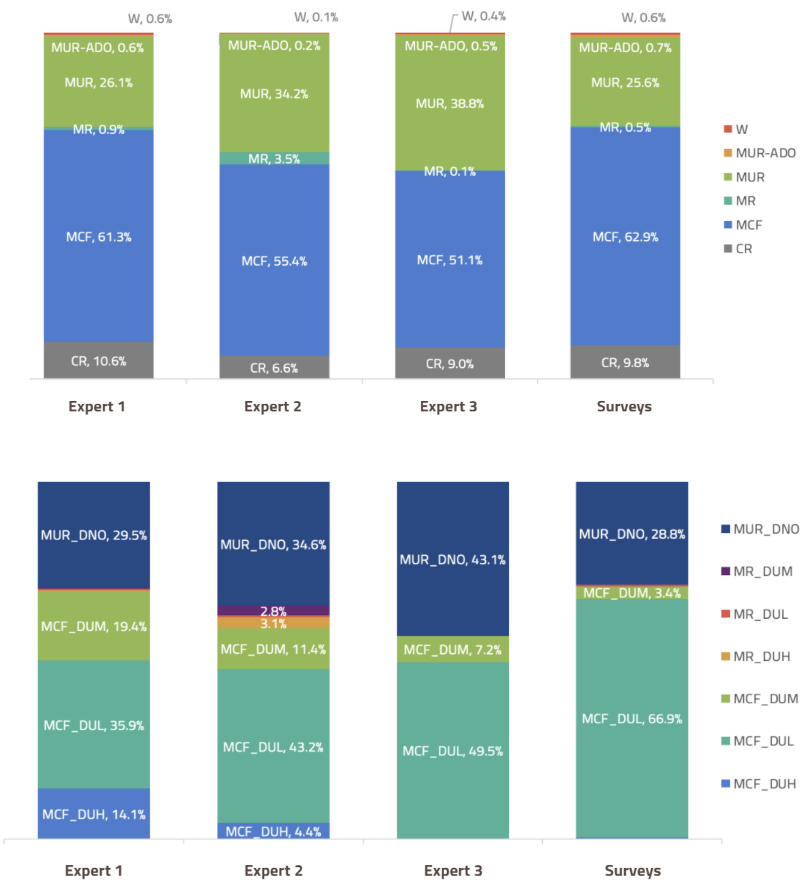


Figure 5 (Top) Distribution of the total exposed economic value of Cali in the main building materials, and (Bottom) Distribution of the masonry typology classes, according to the experts and on-site building surveys.

4.2.3 Santiago

According to the most up-to-date information from household surveys (ENAHO, 2018), the predominant building material in Santiago is concrete block masonry and reinforced concrete. Similarly to the other two cities, masonry has different configurations that can range from acceptable levels of reinforcement to low or no reinforcement. The level of reinforcement depends on the neighbourhood and region of the city. Figure 6 presents the distribution of economic value among the main building typologies for different height. Confined (MCF+CBH) and reinforced masonry (MR+CBH) is commonly found in individual housing units of one to two storeys (HEX:1 and HEX:2) in neighbourhoods built after the 60's and 70's (e.g., La Herradura). Newer zones can hold apartment buildings made of masonry ranging from two to four storeys (HEX:2 to HEX:4). Unreinforced masonry of adobe (MUR+ADO) is concentrated in the historical centre of the city (Centro de la Ciudad) ranging from one to four storeys (HEX:1 to HEX:4), whereas unreinforced masonry of concrete blocks (MUR+CBH) is used throughout the city and is commonly found in neighbourhoods of low socio-economic status and slums. However, reinforced concrete apartments have gained popularity in the previous decade and can hold now up to 15% of the residential exposed value. These types of structures are predominant in neighbourhoods of high socio-economic status, such as Cerros de Gurabo and Villa Olga. Steel is widely used for industrial facilities and is the main building class in the industrial zone of the city (Zona industrial).

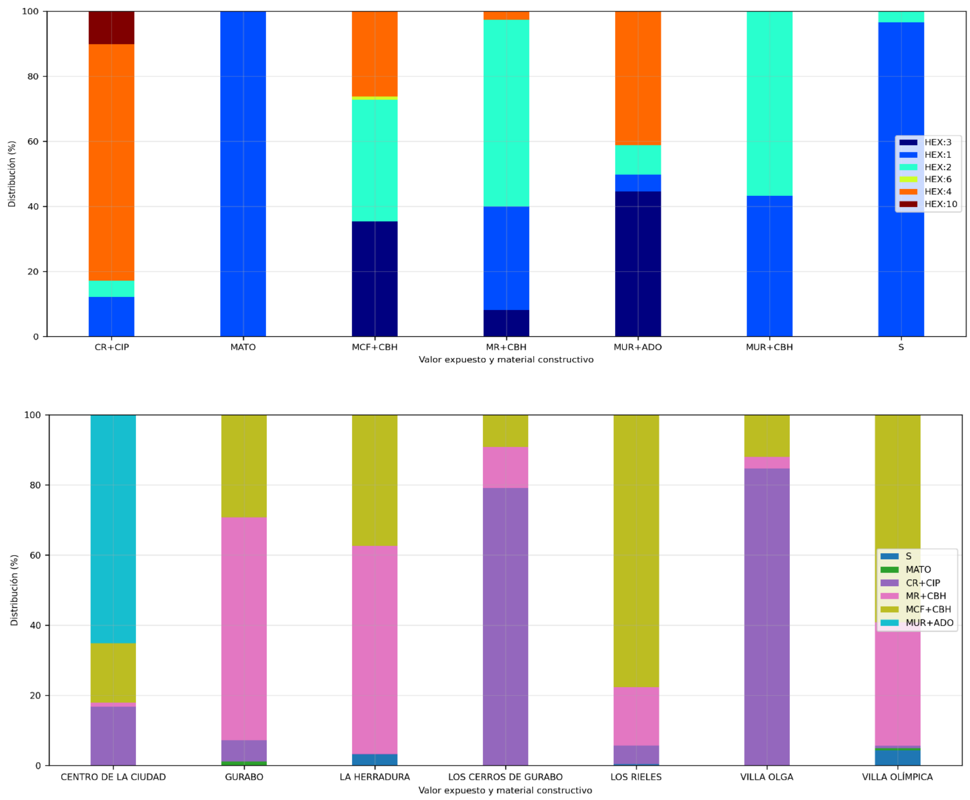


Figure 6. (Top) Distribution of exposed economic value in Santiago in the predominant building classes by height. (Bottom) Distribution of exposed economic in prominent neighbourhoods of the city

4.2.4 List of predominant building classes

Based on the combination of materials, construction systems, number of floors and different levels of excepted ductility, we identified hundreds of buildings classes. The taxonomy mapping files provided for each city (deliverable D2.3.2) contain the full list of typologies and their correspondence to the fragility and vulnerability models assigned to each. For the sake of clarity, Table 1 summarizes the most important classes, aggregated by ranges of construction material, height and ductility level.

Table 1. Description of the main building classes identified in TREQ following GEM taxonomy code (Brzev et al., 2013)

Material	Taxonomy	LLRS	Ductility	Stories
Concrete infilled	CR/LFINF	Infilled frames	Low	1 to 5
Concrete infilled	CR/LFINF	Infilled frames	Moderate	1 to 5
Concrete infilled	CR/LFINF	Infilled frames	High	1 to 8
Concrete infilled	CR/LFINF	Infilled frames	Moderate	4 to 8
Concrete reinforced	CR/LDUAL	Dual	Moderate	6 to 60
Concrete reinforced	CR/LDUAL	Dual	High	6 to 60
Concrete infilled	CR/LFLSINF	Infilled frames	Low	1 to 5
Concrete infilled	CR/LFLSINF	Infilled frames	Moderate	1 to 7
Concrete reinforced	CR/LFM	Moment frames	Low	1 to 4
Concrete reinforced	CR/LFM	Moment frames	Media	1 to 6
Masonry - concrete block	MCF+CBH/LWAL	Walls	Low	1 to 4
Masonry - concrete block	MCF+CBH/LWAL	Walls	Media	1 to 4
Masonry - concrete block	MCF+CBH/LWAL	Walls	High	1 to 6
Masonry - concrete block	MCF+CBH/LWAL	Walls	Media	1 to 6
Masonry - concrete block	MCF+CBH/LWAL	Walls	High	1 to 6
Masonry - concrete block	MUR+CBH/LWAL	Walls	Low	1 to 3
Masonry - brick block	MCF+CLBRS/LWAL	Walls	Low	1 to 3
Masonry - brick block	MCF+CLBRS/LWAL	Walls	Media	1 to 5
Masonry - brick block	MCF+CLBRS/LWAL	Walls	High	1 to 5
Masonry - brick block	MCF+CLBRS/LWAL	Walls	Media	3 to 5
Masonry - brick block	MCF+CLBRS/LWAL	Walls	High	3 to 5
Masonry - brick block	MUR+CLBRS/LWAL	Walls	Low	1 to 3
Adobe	MUR+ADO/LWAL	Walls	Low	1 to 5
Bahareque	W+WWD/LWAL	Walls	Low	1 to 2
Wood	W+WLI/LWALL	Walls	High	1 to 3
Unknown	MATO	Unknown	Low	1 to 2
Steel	S/LFM	Moment frames	High	1 to 3
Steel	S/LFBR	Braced frames	High	8 to 60
Concrete	CR+PCPS/LFM	Moment frames	Moderate	1 to 4
Concrete	CR+PCPS/LFM	Moment frames	High	1 to 4

4.3 Methodology for exposure model development

Developing the exposure datasets requires the processing of the data collected and deriving attributes that can be used to classify assets by their vulnerability, occupancy type and replacement cost. For Quito and Santiago, we used the mapping scheme approach proposed by Yepes-Estrada et al. (2017). The methodology consists of using categorical variables describing the assets and occupants (e.g., building material or socio-economic status) and using them for building classification. The higher the amount and quality of the variables describing the assets, the better the classification. For every structure, we analysed variables like the wall material, the structure material, the floor type, the roof type, the finishes, the year of construction, the height, the economic purpose, the main use of the structure, the construction area and the socio-economic level. In Table 2 we provide an example of how variables were used to infer one or more attributes of the construction type, occupancy type and the replacement cost. The combination of all attributes makes up the final building class of the structure. In the case of Cali, three experts provided classification schemes for the city. These offered a direct way to move from database variables to building classes per city lot based on their expert judgement. After all buildings have been classified, the result is a georeferenced database featuring the exposed assets, with their respective location, vulnerability class, occupancy type, number of occupants and replacement cost. Each city exposure dataset is described in more detail in the following paragraphs.

Table 2. Database categorical variables (left column) used to identify one or more attributes of construction type, occupancy type and replacement cost (top rows), on a structure-by-structure basis for the development of the exposure model for Quito.

	Structural attribute in GEM taxonomy							
Database variable	material	llrs	code	height	year	roof	occupancy	repl_cost
Comunal							Used	
Privado							Used	
Edad					Used			
Pisos				Used				
Acabados								Used
Armazon	Used	Used	Used					
Cubiertas						Used		
Estados								Used
Mamposteria	Used							
Paredes								Used
Principal								
Tipocon							Used	
Usos							Used	
Ventanas								Used
Vidrios								Used
Zona								Used
Destino-economico							Used	Used
Cat_uso-principal	Used	Used	Used				Used	

4.3.1 Considering uncertainties in exposure

During the TREQ project, we identified that even highly detailed databases with construction information, such as cadastre databases, may lack reliable information about specific building attributes. For example, comparing on-site surveys with city records in Quito, attributes as building facades and construction material were highly consistent with the actual structure, but building height and construction area were less consistent. This can be attributed to pending updates of the databases or informal building expansions not reported to city authorities. On another hand, some experts may classify structures based on database variables differently than other experts due to their own experience and judgement. Hence, in TREQ we implemented a method to explicitly account for uncertainty in the vulnerability classification of structures, introduced by relying on dataset variables or expert judgment. As a result, each city has a set of four exposure models, each one representing a specific modelling hypothesis.

4.3.2 Implementation of historical center in Quito exposure database

The historical centre of Quito is one of the best-preserved assemble of Spanish colonial structures in Latin America (Andrade et al. 1991). During the years 2018 and 2019 professor Carlos Celi from the Pontificia Universidad Católica de Ecuador (PUCE), together with a group of students surveyed over 2,000 structures of culture heritage to develop a building-by-building exposure model for the parish of "Centro Histórico". This model has been incorporated to the city exposure dataset developed for Quito. A subset of the model is provided in Figure 7.

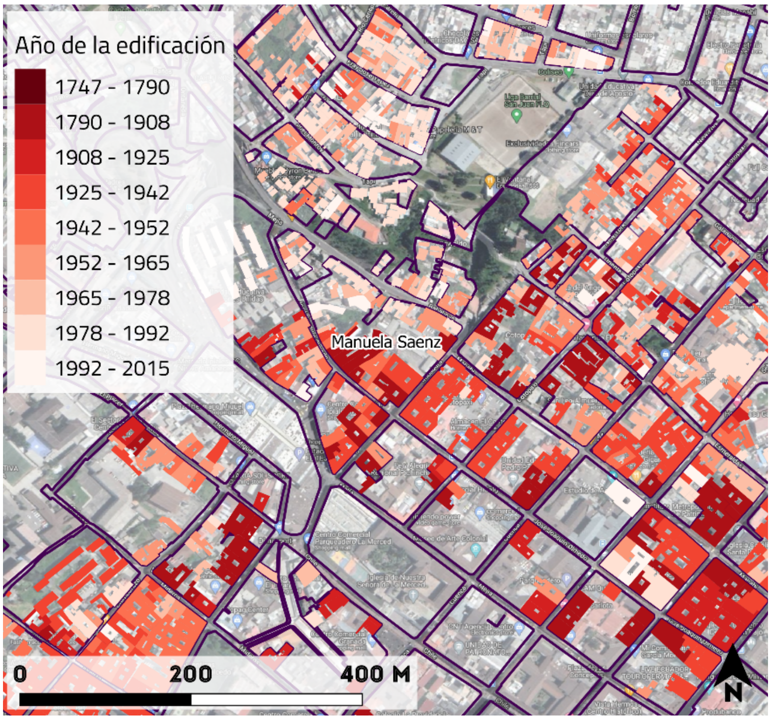


Figure 7. Building-by-building exposure model for the historical centre, developed by professor Celi and incorporated into the TREQ exposure dataset for Quito.

4.4 Quito exposure dataset

The Quito exposure dataset contains over 276,000 structures and more than 2.1 million occupants. These were classified in 373 building classes. Besides residential, commercial and industrial assets, the dataset features the educational (kinder garden, primary schools, high schools, universities and colleges), healthcare (pharmacies, clinics and hospitals) and institutional (government, police departments, firefighting departments) assets. Public and private sectors are included. The total exposed economic value estimated for the city is over 55 billion USD. The average replacement cost per square meter ranges from 376 USD/m² to 540 USD/m² in residential and commercial assets. Educational, governmental, and healthcare assets have higher replacement costs that can range from 560 USD/m² to 1680 USD/m².

In this report the exposure and risk metrics are presented at the official administrative levels. Quito is divided in 11 administrative zones, 65 parishes and 1045 neighbourhoods. The exposure map for the city can be found in **Figure 8** at the neighbourhood level. Maps are also available for parishes and administrative zones.

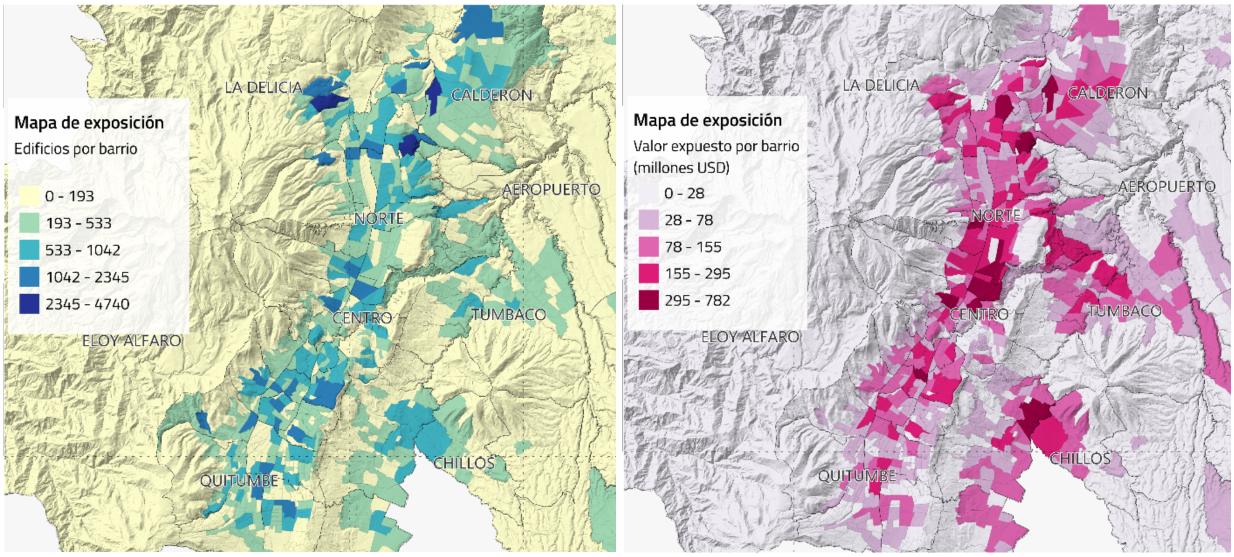


Figure 8. Exposure model for Quito featuring the total number of identified structures (left map) and the total exposed economic value (right map), reported at the level of city neighbourhoods.

4.5 Cali exposure dataset

The Cali exposure dataset contains over 348,000 structures and 2 million occupants. The local experts classified the structures in 6,000 different building classes. This model also includes educational, healthcare and institutional assets from public and private sectors. It has a total exposed economic value over 53 billion USD. It was concluded that in Cali construction costs in residential assets are more dependent on the economic income level of the occupants rather than the construction material or technology. Hence, the average replacement costs per square meter vary from 178 USD/m² to 694 USD/m² through 6 different categories of socio-economic levels. The city of Cali is divided into 22 communes and 334 neighbourhoods. **Figure 9** presents the exposed number of structures and economic value aggregated at neighbourhood level.

4.6 Santiago de los Caballeros exposure dataset

The exposure dataset for Santiago has more than 126,000 structures and 595,000 occupants. Over 160 different building classes were identified in the modelling process. This dataset also features residential, commercial, industrial, healthcare, institutional and education assets from private and public sectors. The total exposed economic value is 25 billion USD. Work for Santiago focused on updating the replacement costs for the city taking into consideration the increase in construction costs caused by the high demand for housing in the country in the last decade. In the current values, replacement costs per square meter in the city range from 340 USD/m² to 770 USD/m² for residential assets, depending on the quality of construction and finishes. Costs for educational and healthcare sectors are among the highest, ranging from 490 USD/m² to 1500 USD/m².

For Santiago assets have been included beyond the administrative boundaries of the municipality at the request of the Office of Urban Planning (POT). Besides the metropolitan district of Santiago de los Caballeros, neighbourhoods from five other surrounding districts, namely Canabacoa, Las Palomas, Puñal, Licey al medio, San Francisco and Tamboril. There is a total of 443 neighbourhoods in the dataset. Th exposure model featuring all neighbourhoods considered in the analysis is presented in **Figure 10**.

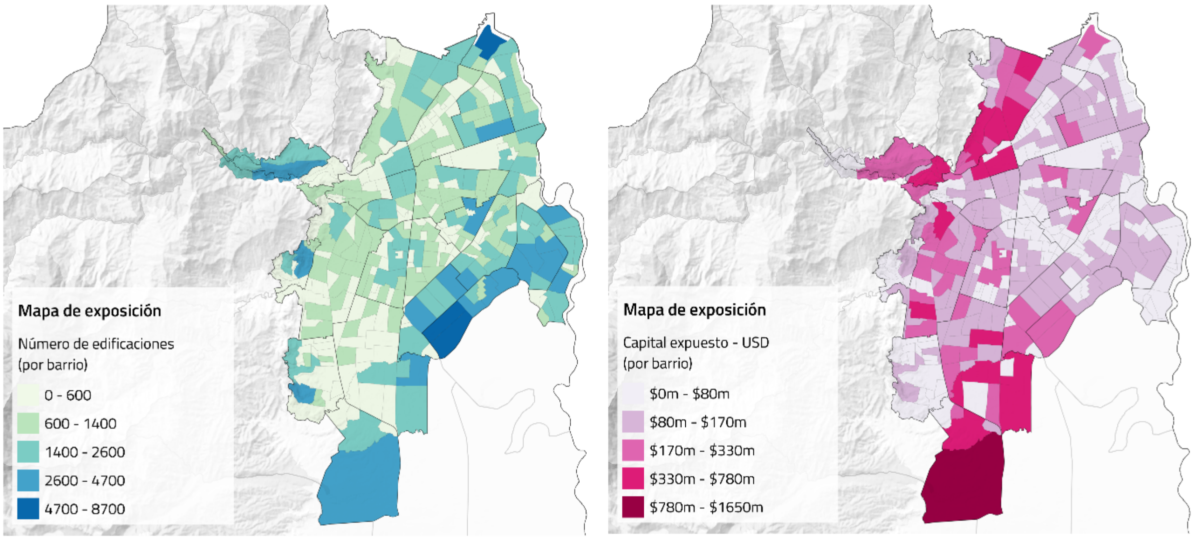


Figure 9. Exposure model for Cali featuring the exposed economic value. The left map presents the original resolution of the model. The map on the right presents values aggregated per neighbourhood as intended for risk communication purposes.

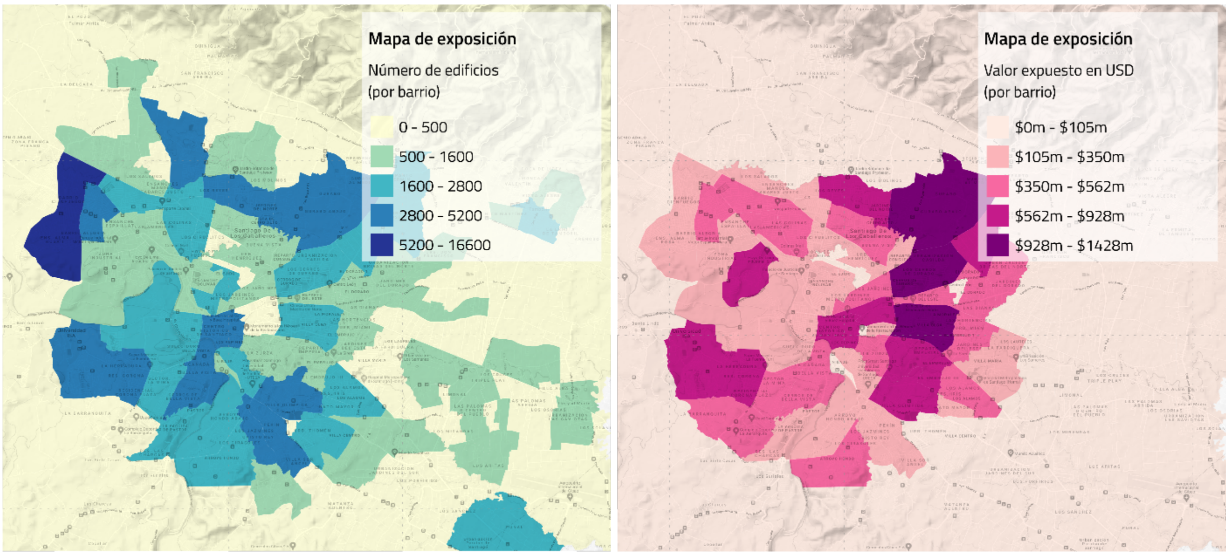


Figure 10. Exposure model for Santiago featuring the exposed economic value. The left map presents the original resolution of the model. The map on the right presents values aggregated per neighbourhood as intended for risk communication purposes.

5 VULNERABILITY CLASSIFICATION AND DATASETS

The assessment of damage, economic losses and fatalities require a set of fragility and vulnerability models for the building classes found in the exposure. A fragility function represents the probability of exceeding a level of damage conditional on ground shaking intensity. These are used to make estimates of damage, like damage distribution statistics and maps of building collapse. On the other hand, a vulnerability function defines a probabilistic distribution of loss ratio (e.g., mean loss ratio and the corresponding coefficient of variation) conditional on the ground shaking intensity, which can be used to estimate losses, such as economic loss statistics and maps of human fatalities.

The use of fragility and vulnerability models that capture the city specific design and construction practices is not yet possible given the limited number of models available. Ecuador and Colombia have previous studies for different classes of masonry and concrete structures (e.g. Garcia and Degrande, 2017; Acevedo et al., 2017). However, these focus on structural fragility and vulnerability and cannot be used to estimate human losses. Furthermore, the models in literature do not cover the occupancy classes indicated in Table 1. In the case of Santiago, the availability of models is still limited to empirical relationships not adequate for estimates of either economic or human losses. Therefore, we have used from the GEM global vulnerability database (Martins and Silva, 2020). Details of the vulnerability database and additional efforts for developing local models in the cities are presented in the following sections.

5.1 GEM global vulnerability database

The GEM global vulnerability database is a set of functions derived with uniform methodology for a wide range of building classes. It provides fragility curves that allow the estimation of physical damage in buildings, as well as a set of consequence models for the estimation of structural and human loss ratios. Moreover, these are available for several intensity measure types (IMTs) that range from PGA to spectral accelerations (Sa) at periods of vibration of 0.3 seconds, 0.6 seconds and 1 second.

As an example, **Figure 11** provides two fragility models, in the top panel, for reinforced masonry (MR) and infilled reinforced concrete frames (CR/LFINF) for two storeys structures (HEX:2), which have been mapped to the same classes identified in Quito, Cali and Santiago. The fragility functions were later converted into vulnerability functions using the damage-to-loss model proposed by Yepes-Estrada and Silva (2017) for economic losses due to direct damage. The bottom part of the same figure provides the resulting vulnerability models for the same two classes. In these models the loss ratios follow a beta distribution, thus allowing the propagation of the uncertainty from the vulnerability component into the risk assessment. For the derivation of vulnerability functions in terms of loss of life, the probability of collapse given complete damage was first estimated (from evidence from past earthquakes as well as recommendations from HAZUS—Federal Emergency Management Agency (FEMA), 2007) and then the fatality ratios proposed by Spence (2007) were adopted. The reader can find all the fragility and vulnerability models used for TREQ in the deliverable *"D.2.3.3 Database of fragility and vulnerability functions".*

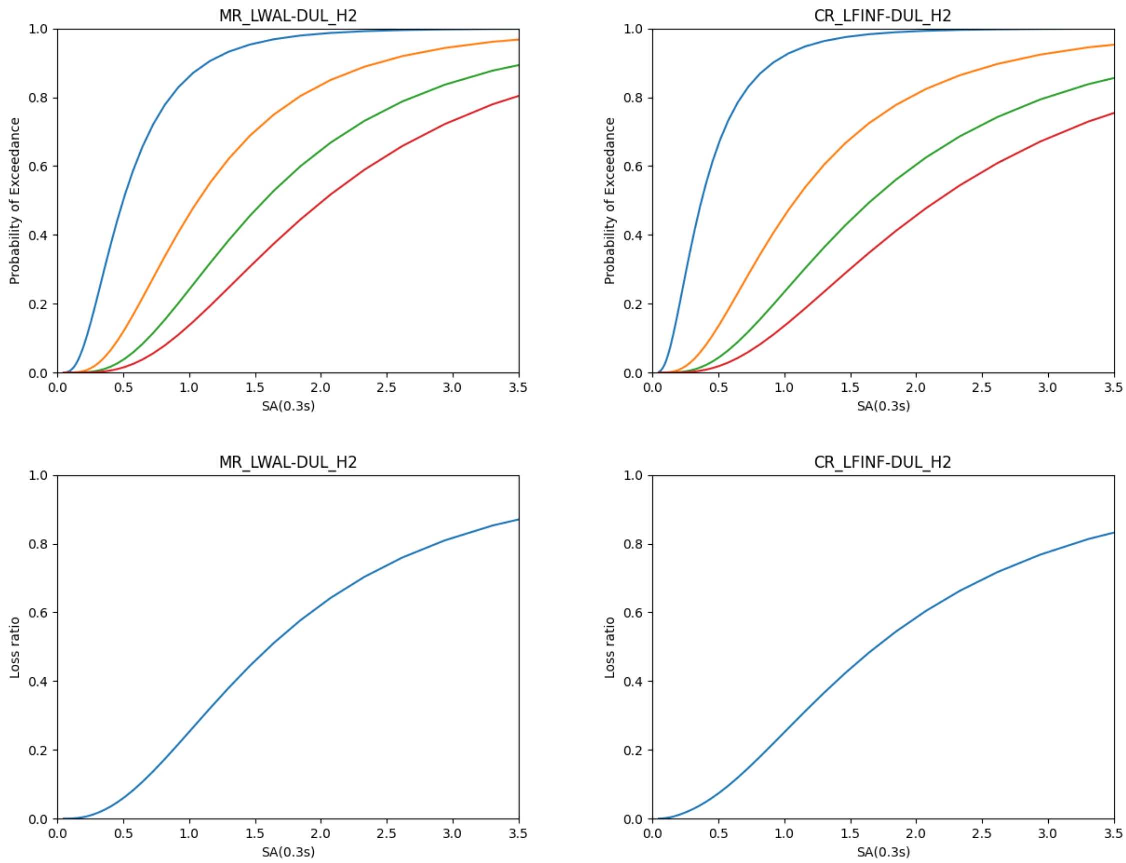


Figure 11. (Top) Fragility models used for the estimation of building damage for reinforced masonry (MR) and infilled reinforced concrete frames (CR) of low expected ductility (DUL) and two storeys height (HEX:2). (Bottom) Structural vulnerability models used for the estimation of economic losses for the same building classes.

The fragility models were developed accounting for the record-to-record variability, the uncertainty in the damage criterion, and the building-to-building variability using an analytical methodology for the definition of the structural capacity of each building class. In this process, a capacity curve is defined based on the structural and dynamic properties of each building class (yield and ultimate drifts, elastic and yield period of the first mode of vibration, participation factor of the first mode of vibration, common failure mechanisms). These capacity curves were used to develop a single-degree-of-freedom (SDOF) oscillator for each building class, and each SDOF oscillator was subjected to nonlinear time history analyses using 300 ground motion records. In order to propagate the record-to-record variability of the vulnerability models, a large set of time histories was used. The structural response from the SDOF oscillators (i.e. the maximum displacement was used as the engineering demand parameter (EDP) was plotted against the IM of each ground motion record to establish a relation between demand and response, following the cloud analysis approach (Jalayer et al., 2015). Then, the probability of exceeding a set of damage states (slight, moderate, extensive, and complete) was calculated assuming a damage criterion based on the yielding and ultimate displacement points, as described in Villar-Vega et al. (2017). These probabilities versus IMs were used to fit a cumulative lognormal distribution (i.e., fragility curve) using the maximum likelihood method (Baker, 2015).

We have found that the available fragility and vulnerability are approriate for the predominant building classes of masonry and reinforced concrete identified in Quito, Cali and Santiago. For instance, over 80% of the buildings and occupants in Quito are concentrated in the building classes presented in Figure 12. Structures of infilled concrete frames (CR+CIP/LFINF) and unreinforced masonry (MUR) of low ductility (CDL) ranging from two to four stories (HEX:2 to HEX:4) require fragility models derived short spectral acceleration periods (e.g., 0.3 seconds), whereas tall structures of concrete (CR+CIP/LDUAL+CDL/HBET:11-20) need fragility models derived for longer structural periods (e.g., 1 second). These building typologies and IMTs are covered in the GEM global vulnerability database.

Figure 12. Distribution of exposed economic value in the top 12 building classes in Quito. Over 50% of the value is concentrated in masonry building classes of one to three storeys.

5.2 Development of local fragility models

Addition efforts are undergoing to develop local functions. For example, seismic fragility for the most important building classes is under study by academic groups in the Universidad de las Fuerzas Armadas del Ecuador (ESPE), based on the findings of the urban exposure models. Figure 13 and Figure 14 present two examples of numerical models for different configurations of the infilled reinforced concrete frame building class commonly found in Quito.

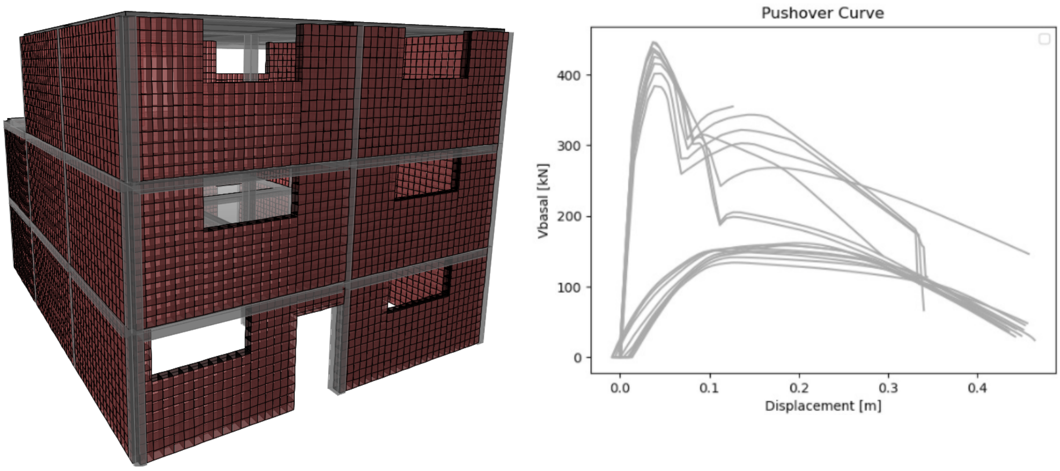


Figure 13. (Right) Tridimensional numerical model for three-storey infilled reinforced concrete frame building of low and moderate ductility commonly found in Quito. (Right) Capacity curves considering the building-to-building variability in the configuration of the lateral load resisting system. This model is under development by Mauricio Guamán and José Poveda in ESPE, within the context of the TREQ activities with the academia in Quito.

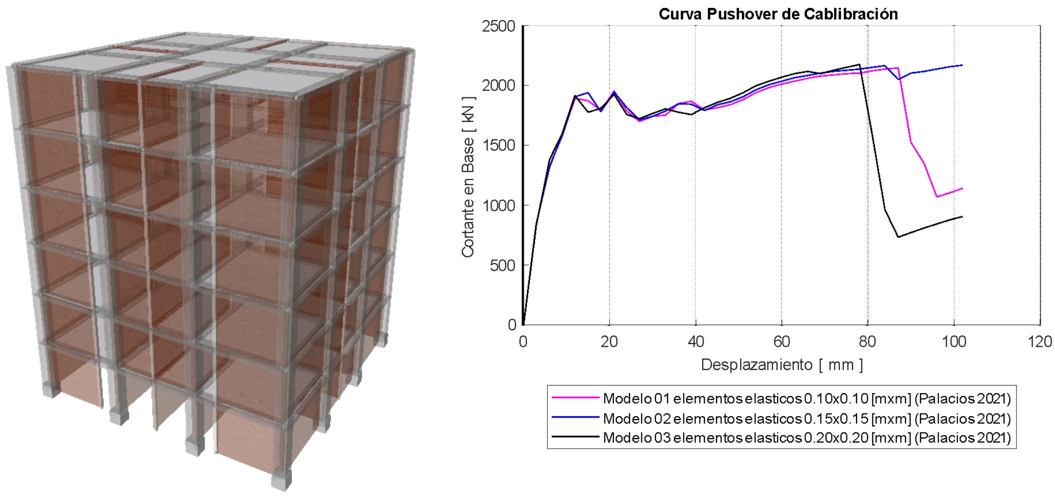


Figure 14. (Right) Tridimensional numerical model for four-storey to six-storeys infilled reinforced concrete frame buildings of low and moderate ductility commonly found in Quito. (Right) Capacity curves considering the building-to-building variability in the configuration of the lateral load resisting system. This model is under development by Patricio Palacios and Carlos Celi in the Pontificia Universidad Católica del Ecuador, within the context of the TREQ activities with the academia in Quito.

6 PROBABILISTIC SEISMIC RISK

6.1 Methodology

The probabilistic seismic risk assessment for Quito, Cali and Santiago was performed using the event-based risk calculator of the OpenQuake engine (Silva *et al.* 2014). The engine uses the PSHA models to generate several possible realizations of seismicity conditioned on an investigation time (i.e., stochastic event sets or SES). The events are generated using the same magnitude-frequency relationships established for each source in the seismogenic model by means of a Monte Carlo sampling process. Each rupture generated is fully defined by a magnitude, upper and lower seismogenic depth, hypocentre, and dip, rake and strike angles. 100,000 SES with a 1-year duration were generated per logic three branch in the PSHA models for Quito and Cali, whereas for Santiago the same amount of SES was generated for 100 branches (given the complexity of the hazard logic tree). This length of the SES ensured statistically reliable results for the estimation of average annual losses and losses for return periods up to 1000 years (Silva 2017). Considering the logic tree of GMPEs in the PSHA models, a ground motion field (GMF) was generated for each event. In this process, the inter-event variability from the ground motion prediction model is sampled once per rupture, whilst the intra-event variability is sampled for each location considering the spatial correlation in the ground motion residuals (Jayaram and Baker 2009). The ground shaking intensities were estimated at: i) the bedrock using a reference Vs30 value of 800 m/s, ii) the surface using the Vs30 values obtained from the proxy datasets, and iii) the surface using the site amplification models developed for each city (see ***3.1* Seismic hazard and site response models** for more details on each assumption).

The adjusted intensities were used to compute three metrics of risk, namely **building damage**, **economic losses, and human losses** per event in the SES. Building damage, presented herein as collapses due to ground shaking, was obtained using the GVM fragility models. Economic losses (in United States dollars – USD) and human fatalities were obtained by multiplying the structural and occupants' loss ratios from the vulnerability models by the exposed economic value and occupants of each building class respectively. The epistemic uncertainty associated to the hazard and exposure models is explicitly considered in the estimation of risk, by generating a GMF per logic-tree branch. In this section the main findings are discussed together with the main conclusions about the factors driving the risk in each urban centre. Most of these results have been discussed with the technical groups of the cities, and further work will focus on the communication of risk metrics and the generation of city profiles to support the risk management offices. Additional maps and figures of risk results are available in the deliverable "*D.2.3.4 Maps and risk metrics*" for further reference.

6.2 Loss exceedance curves

Two main risk outputs were derived from the event-based analysis, namely loss exceedance curves for the building portfolios and average annual losses. Loss exceedance curves are generated by estimating the annual rate of exceedance of a given risk metric $\lambda(L > l)$, as described by the following equation:

$$\lambda(L > l) = \frac{1}{n}\sum_{i=1}^{j} I(L_i > l) \quad (1)$$

The relation between the different levels of loss (collapsed buildings, economic or fatalities), and their respective rates of exceedance (transformed herein to return periods) were used to produce loss exceedance curves of each portfolio under analysis. Figure 15 presents the results for the building portfolio of Quito, considering all possible realizations (grey curves) and the weighted average curves obtained for each zone in the microzonation study (M1 in white to M12 in dark blue).

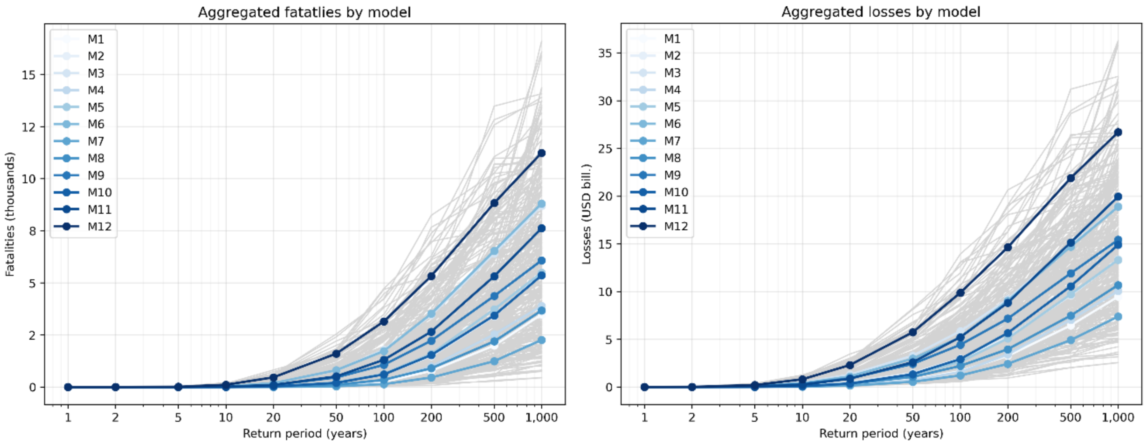


Figure 15. Loss exceedance curves for the city of Quito, featuring the epistemic uncertainty in the estimation of the human (left) and economic losses (right) by considering the all the model hypothesis (in grey), and the average curve obtained per exposure model and site response model (from white to blue).

Table 3 summarizes the expected economic losses human fatalities and number of collapsed buildings for different return periods, when considering the site models with amplification factors. Quito and Cali are cities with similar population size, around 2 million inhabitants, and the same order of magnitude in terms of buildings and replacement cost. However, significant differences in the expected number of human fatalities arise from the building characterisation, its vulnerability and the seismic hazard.

Table 3. Expected economic losses and human fatalities for different return periods

		Quito	Cali	Santiago
Economic Loss (USD mill.)	RP-50y	3203	583	624
	RP-200y	8983	1971	3631
	RP-500y	13776	3229	5816
Fatalities	RP-50y	766	80	55
	RP-200y	3280	421	539
	RP-500y	6080	824	996
Collapses	RP-50y	716	152	182
	RP-200y	2967	804	1748
	RP-500y	5308	1572	3282

In terms of absolute risk, Quito is the city presenting the highest risk estimates. In comparison to Cali, the economic losses for the 200 years return period are four times higher, and up to eight times higher in terms of human fatalities. Several factors contribute to the difference in the results: i) the expected seismic hazard at bedrock in Quito is higher; ii) the soil model indicates amplification for all IMT and all periods, while in Cali most of the zones exhibit low amplification levels; iii) the built environment is in general more vulnerable than the one in Cali. On the other hand, Santiago de los Caballeros despite having around 30% of the occupants and between 50-65% of the exposed value in comparison to Quito and Cali (e.g., ~600 thousand occupants versus 2.0 million), has a similar level of relative loss compared to Quito (i.e., losses divided by the exposed value); for the 200 years return period, the expected relative economic losses in Quito, Cali and Santiago are 16%, 5%, and 14% respectively.

To further explore the influence of local site response in the risk metrics, Figure 16 presents the mean exceedance curves for each city, considering the three possible site models (rock, vs30 from proxies and amplification functions). It can be observed that Quito is the city with the highest impact in the risk estimates when considering local site models, increasing the economic losses and human fatalities by a factor of 1.8. In the case of Cali and Santiago de los Caballeros, the loss exceedance curves using site amplification factors are lower than the ones using vs30 proxies. In Cali, human losses are reduced by a factor of 2.2 with respect to the estimates using vs30 proxy datasets developed by the USGS or the Colombian Geological Survey (SGC).

Comparing estimated at bedrock (i.e., excluding site amplification effects), Quito is the city presenting the highest risk estimates. In comparison to Cali, the economic losses for the 200 years return period, are two times higher, and up to four times higher in terms of human fatalities. On the other hand, Santiago de los Caballeros exhibits the largest human fatalities in absolute terms, but it has despite differences in the population size. When comparing relative values at bedrock, Santiago is the city with the largest affected population for a 200-year return period, i.e. expected fatalities divided by the total population.

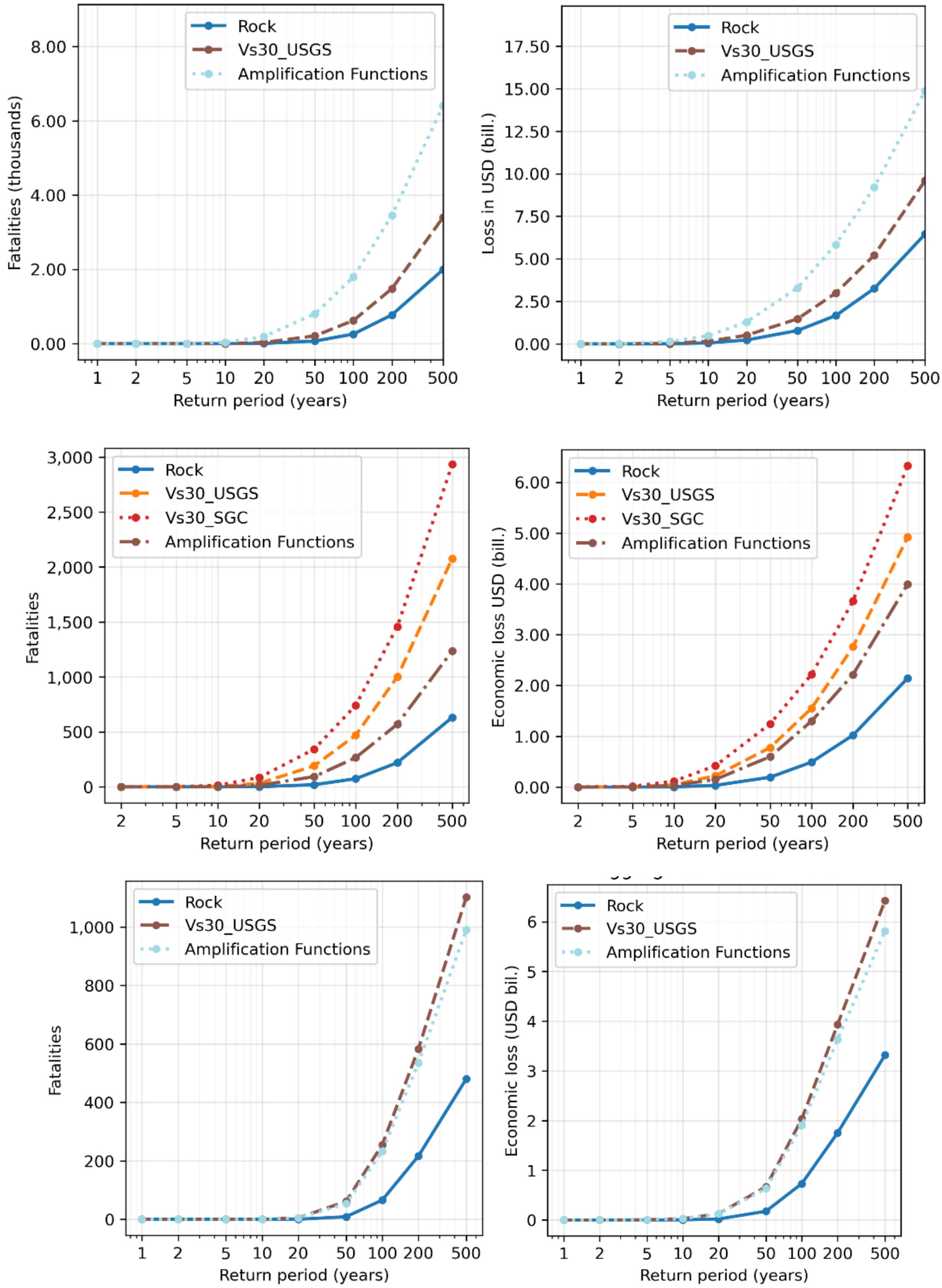


Figure 16. Average los exceedance curves up to a return period of 500 years for human and economic loss for Quito (top), Cali (centre) and Santiago (bottom), according to the different site response models. For Cali, an additional site response model is included, corresponding to the Vs30 estimates by the SGC.

6.3 Average annualized losses

The average annual risk metrics were obtained by adding the losses from all SES per logic tree branch, and dividing the result by the total investigation time (i.e., number of 1-year SES), as described in the following equation:

$$\underline{AL_n} = \frac{1}{n}\sum_{i=1}^{j} L_i \qquad (2)$$

Here, L_i represents the loss for rupture *i*, *j* is the total number of seismic ruptures and *n* represents the total length of the SES. For the TREQ cities, metrics of absolute risk, such as the average annual economic losses (AAL), the average annual fatalities (AAF) and the average annual collapsed buildings (AAC), were estimated using 100,000 SES. Metrics of relative risk were obtained by dividing the absolute results by the exposed economic value, exposed number of occupants per 100,000 inhabitants (as required by the Sendai Framework, UNDRR 2015), and by the number of exposed buildings, respectively. These metrics can be reported at a city level, for a certain administrative subdivision or per exposed asset. Herein the geographical distribution of the losses is being reported at the neighbourhood level, which is the smallest administrative division in the three cities.

The city of Quito has an average annual economic loss ranging from $133 million USD to $288 million USD, when considering amplification through Vs30 proxy models and amplification functions, respectively. That amounts to a relative loss of 0.24% to 0.52% of the total exposed economic value. The distribution of the absolute and relative risk metrics (AAL and AALR) is presented in Figure 17 when considering the amplification functions. In absolute terms, losses for the city concentrate in central and north neighbourhoods. Central zones that concentrate commercial activity and high-end construction like Mariscal Sucre, La Padrera and Benalcazar present AAL values that range between 0.3 and 0.8 million USD when site amplification is being considered. Northern neighbourhoods like Carapungo, Comité del Pueblo and Ponceano Alto also have levels of loss above 0.5 million USD due to the density of residential construction. In terms of relative risk, the neighbourhoods with the highest loss ratios are located in the historical centre of the city. The most notable of these are El Panecillo and Gonzáles Suárez. A group of neighbourhoods in the northwest of the city, by the Bicentenario park also present significant levels of relative loss. This is a zone of high seismic amplification due to the soil's characteristics.

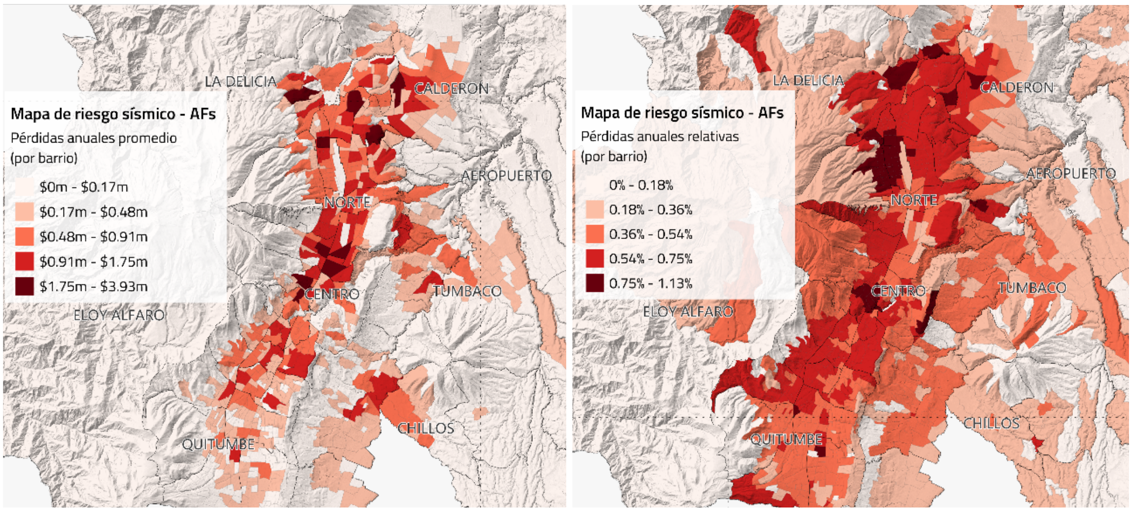


Figure 17. (Left) Map of average annual economic losses (AAL) for Quito per neighbourhood, highlighting zones with concentration of great economic value like Mariscal Sucre. (Right) Map of relative economic losses (AALR), highlighting zones with high potential of loss in their exposed value, like the Centro Histórico, were most of the structures are made of unreinforced masonry of adobe and clay bricks. These results were obtained using the site amplification functions (AFs) developed for the city.

The average annual number of fatalities (AAF and AAFR) for Cali are presented in **Figure 18**. Due to the amount occupants, the most populated neighbourhoods in the city are highlighted with the potential of human loss. These zones are scattered through the city. For example, Parcelaciones Pance, Ciudad Córdoba, Mariano Ramos, Terrón Colorado and Ciudadela Floralia all have AAF numbers above 0.08. West and central neighborhoods like Sector Alto Jordán and El Guabal also have significant AAF due to the physical vulnerability of their exposure. However, in terms of relative human loss, the central neighborhoods highlight above the rest of the city. There is a combination of low socio-economic status and high amplification of seismic intensity that causes high relative losses in region like San Antonio, San Pascual, Sucre and Guayaquil (all above 1 death per 100,000 inhabitants).

The maps in Figure 19 presents the distribution of the absolute and relative average annual collapses in Santiago de los Caballeros. In absolute terms, the western neighbourhood Cienfuegos has the highest number of collapses within the period of seismicity. Even though in administrative terms Cienfuegos is outside the urban area, this region concentrates the highest number of inhabitants and residential structures in the exposure dataset. It is estimated that over 50,000 people currently lives in this zone as of 2020 (ONE 2011, ONE 2020). Together with Cienfuegos, Monte Rico, La Joya and Centro de la Ciudad (the historical center) present over 1.0 average annual building collapse. Similar to Quito, when risk is analyzed in relative terms, the neighborhoods within the oldest regions of the city (construction year ranging from 1900 to 1950) are the focus of the highest relative metrics, average annual collapses above 0.05% of the structures in Centro de la Ciudad, La Joya, La Otra Banda, Pueblo Nuevo and Baracoa.

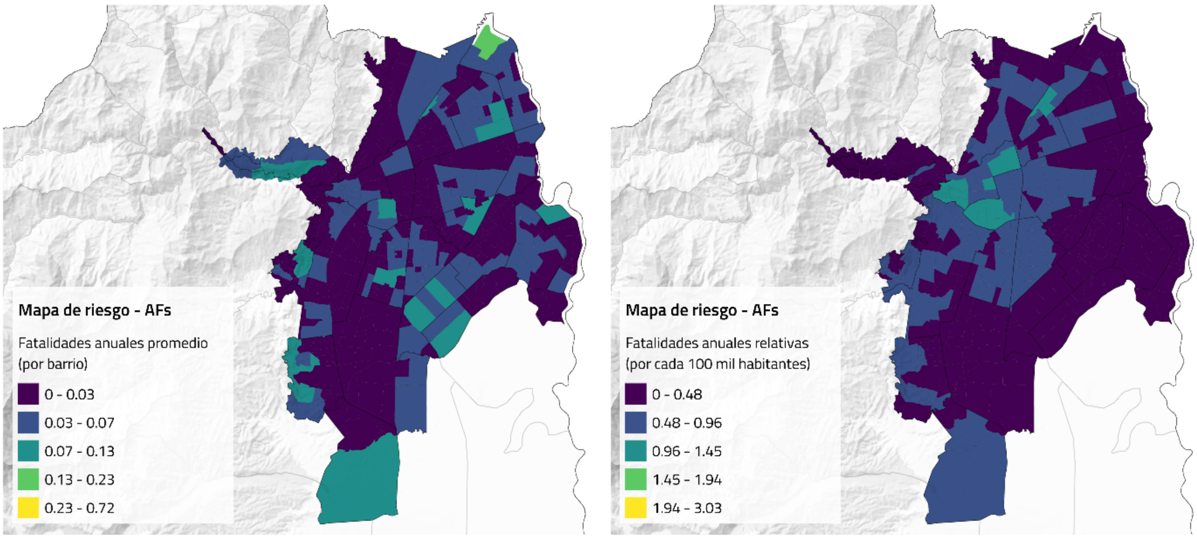


Figure 18. (Left) Map of average annual fatalities for Cali per neighbourhood, highlighting zones with concentration of occupants and assets, like El Morichal, and Terrón Colorado. (Right) Map of human losses per 100,000 inhabitants, highlighting zones with high potential of loss of human life, like Sucre and Guayaquil.

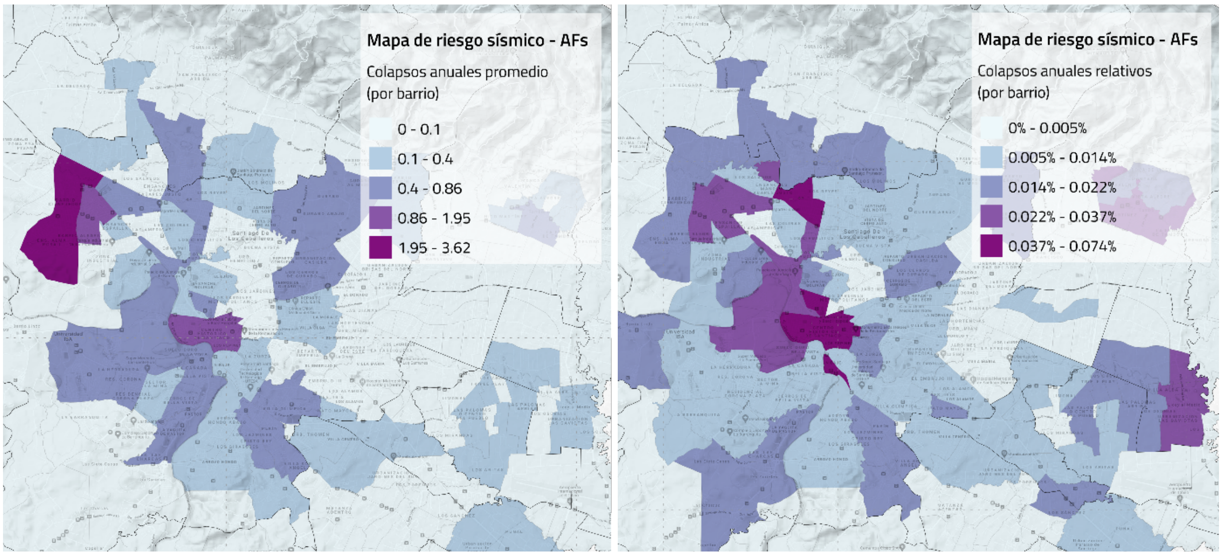


Figure 19. (Left) Map average annual collapses per neighbourhood in Santiago de los Caballeros, highlighting Barrio Cienfuegos, the most densely populated region in the study area. (Right) Map of relative annual collapses, highlighting the oldest region in the city like Centro de La Ciudad, La Joya, Pueblo Nuevo, and Baracoa.

6.4 Analysis of the urban risk drivers

Quito has the highest risk metrics of the TREQ cities. Excluding the effect of any site response model, the analysis of risk assuming a uniform quality for the soil (Vs30 of 800 m/s) for Quito results in higher damage, economic loss and human loss statistics. This can be attributed to the higher seismic hazard and the vulnerable built environment. Most of the exposed assets and occupants are in areas of an expected PGA above 0.50g for a return period of 475 years. Moreover, the exposure results suggest the city has the highest number of structures of unreinforced masonry or low ductility reinforced concrete infilled frames with two and three storeys. When considering the amplification of the ground motion intensity using the site response models, the estimated risk in relative terms can increase from two to four times the values on rock. That is because the local site model for the city suggests significant levels of amplification (above 2.5) for most ground shaking intensity ranges and the most common structural type (with Sa0.3s) in the zones of MSQ2, MSQ10 and MSQ11. These three zones together hold over 60% of the total exposed economic value and occupants of the city (see Figure 20).

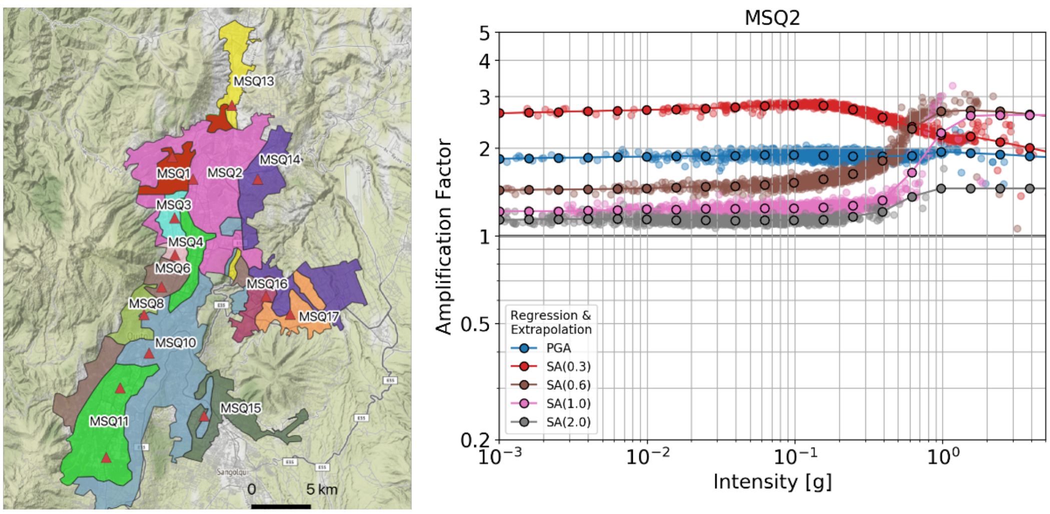


Figure 20. Site response model for MSQ2 in the city of Quito, displaying values of amplification over 3 for most ground motion intensity ranges, in a region holding over 20% the exposed assets in the structural period of Sa(0.3s). The same occurs in zones MSQ10 and MSQ11, which hold in addition 40% of the exposed assets.

Cali on the other hand, exhibits lower levels of risk when amplification functions are used. In this case site response models using AFs suggests much moderate amplification effects. For example, in the case of Microzones 5 and 6, the amplification is below 2.0 for low to moderate ground shaking intensities, and there is strong deamplification (below 1.0) for high ground shaking intensities, over all structural periods. These two regions alone hold around 60% of the exposed occupants and structures in the city. This effect is not observed when risk is estimated using vs30 proxy values, as such site response models do not consider the non-linearity of the soil profiles in the city micro seismic zones.

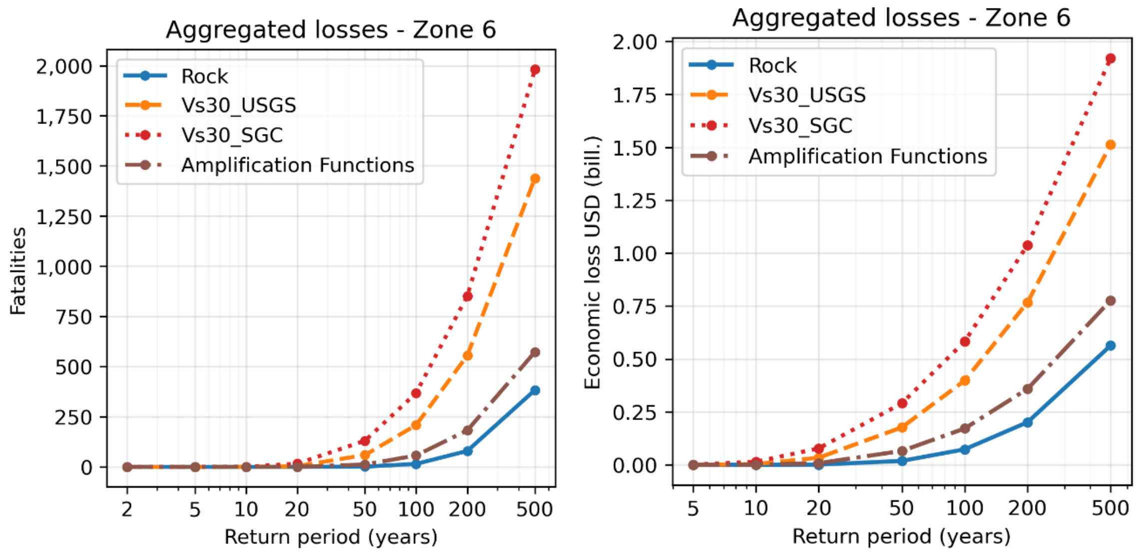


Figure 21. Loss exceedance curves for fatalities (right) and economic losses (left) in seismic zone 6, which hold over 40% of the exposure in the city of Cali. The risk metrics exhibit a significant decrease when amplification functions are used due to the deamplification of the ground shaking intensity across the predominant structural periods in the exposure (Sa 0.3s and Sa 0.6s).

In the case of Santiago, the use of amplification functions yields slightly lower levels of relative risk in terms of damage, economic loss and human loss statistics. The driver of risk in this case is the proximity of the most vulnerable neighbourhoods, to the northern Septentrional Fault of the Hispaniola Island. Of three cities being studied in TREQ, Santiago has a much higher exposure to the seismic hazard. Over 50% of the city structures are in regions with an expected PGA above 0.55g to 0.65g within a return period of 475 years. Moreover, despite being a durable material resistant to adverse hydro-meteorological conditions in the Caribbean, properly reinforced concrete masonry was found in less than half (47%) of the structures in the city, mostly concentrated in the oldest parts of the city (constructions prior to 1960's). Moreover, despite a recent implementation of a new seismic code in 2011, densely populated neighbourhoods, like the previously mentioned Barrio Cienfuegos still report high levels of informality in their construction.

The urban risk assessment in the TREQ cities shows the importance of hazard, site response, exposure and vulnerability models that capture the details and dynamics of the city. These input models are fundamental for the identification of the main drivers of risk in Quito, Cali and Santiago de los Caballeros. Local site characterization can exacerbate (e.g., in Quito) or reduce (e.g. Cali) the seismic risk estimates when combined with the different building classes present in the different seismic zones of the cities. Furthermore, local models reduce the uncertainty associated with the use of low-resolution proxy datasets and other assumptions commonly present in national and regional scale models. Sensitivity analysis indicated that the quantification of the impact, in terms of the expected economic losses, human fatalities or the number of collapsed buildings at different return periods, can be modified by one or more orders of magnitude. The resulting risk metrics are conditioned to the quality and accuracy of the input models, and therefore it is essential to adequately characterize the seismic hazard, the local soil response, the building inventory and its occupants, and the likely response of the structures under seismic action. Quito is an example of this. It is clear that the use of site response models based on regional scale proxy datasets results in an underestimation of seismic risk in more than 80% of the exposed assets and occupants in the city. In contrast, detailed information about the soil and exposed assets in Cali helped to better identify zones of lower risk. The deamplification of ground shaking intensity in areas with predominant mid-rise and high-rise construction resulted in better estimates of economic and human loss statistics in neighbourhoods that concentrate most of the economic value of the city. Using this information, more accurate city risk profiles have been produced for the risk management offices, which can later be used to inform risk management policies.

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