Development of a Seismic Risk Model for Northern Algeria

Andrés Abarca
Graduate Student, University School for Advanced Studies (IUSS) of Pavia, Italy

Ricardo Monteiro
Assistant Professor, University School for Advanced Studies (IUSS) of Pavia, Italy

Smail Kechidi
Researcher, Faculty of Engineering University of Porto (FEUP), Portugal

José M. Castro
Assistant Professor, Faculty of Engineering University of Porto (FEUP), Portugal

Mario Marques
Researcher, Faculty of Engineering University of Porto (FEUP), Portugal

Abdelkarim Yelles
Director, Reliability Consultancy Inc., City, Country

ABSTRACT: A collaborative effort was made within the scope of the EU project ITERATE to develop a web-based tool for large-scale probabilistic assessment intended to enable Algerian stakeholders to understand and calculate seismic risk though the convolution of hazard, exposure and vulnerability. A great amount of information was collected, organized and processed to determine the characteristics of the Northern Algerian built inventory (buildings and bridges) in terms of quantity, location, typology and structural behavior, using the city of Blida as pilot case-study. Furthermore, the vulnerability of the inventory was evaluated through the development of fragility curves, based on the observed behavior of a great number of nonlinear structural models under the effect of multiple earthquake records, accounting for epistemic and aleatory uncertainties. The developed exposure and vulnerability models, along with an updated seismic hazard model were loaded to a specifically developed web application which allows the probabilistic evaluation of seismic event scenarios, as well as automated predictions in terms of human and economic losses.

1. INTRODUCTION

Given its growing economy and population, Algeria shows enormous potential for development, however, given its geological conditions and history of irregular construction practices, the nation faces a high level of seismic risk which has severely affected its population in the past.

In response to this situation, advances have been made in construction legislation to increase the resilience of the built environment. As an example of this, in 2004 a new version of the seismic code was made available and the country adopted the Law on Prevention of Major Risks and Disaster Management and the National Scheme for Land Use Planning, demonstrating its political will to promote disaster risk reduction (DRR). However, limited resources and capacities, lack of cross-sectoral coordination and, mainly, awareness among several stakeholders have impeded the full implementation of the conceived policies.

As a response to this, and as a part of the European Union initiative to reduce risk among its members and its neighboring countries, the project ITERATE (Improved Tools for Disaster Risk Mitigation in Algeria) was created to focus on disaster risk reduction in Algeria. Its objective is to implement an improved framework for seismic risk assessment that can be replicated to other natural hazards, making use of a privileged combination of scientific expertise in Algeria, Portugal and Italy.

2. METHODOLOGY

Current methodologies for assessing the seismic risk on a large scale are based on the general definition of risk as the convolution of hazard, exposure and vulnerability, thus this research follows that line by developing each one of these components and implementing them in an analysis engine which is capable of integrating them and producing a probabilistic notion of the overall risk in terms of economic losses in a region of interest. Given the restriction of resources (mainly time and data), the development of all components for the entire Algerian country was deemed unfeasible, therefore the analysis engine is built with the availability to be extended and improved, and the research is focused on the city of Blida, chosen as a case study.

The hazard component is accounted by studying the recorded frequency of seismic events with the objective of determining the geological fault sources and its magnitude-frequency properties. Furthermore, ground motion prediction equations are used to determine the effects of a specific event from the source on the geographic level. A probabilistic approach is thus carried out to determine the likelihood of exceedance of any particular intensity in a timeframe, thus leading to a hazard model. In this research, this component builds upon studies previously performed in the Algerian context, updating the existing models with the most up to date information and implementing them in the OpenQuake (Silva et al, 2014) platform.

In terms of exposure, the overall goal is to develop an inventory of existing assets of both buildings and roadway bridges in the chosen area, recording both the amount and construction characteristics of the structures. With this purpose, census information, public institutions, online tools and local expert opinion is consulted and all gathered information is processed to produce a functional database of all the assets of interest whether aggregated on the municipal administrative level (as is the case for buildings) or in terms of individual assets (as is the case of bridges).

The vulnerability component is divided in physical and social sub-components. The physical vulnerability refers to the estimation of the behavior of the structures, while the social vulnerability takes in to account the demographic parameters of the social groups to estimate their ability to cope with a disaster.

The physical sub-component is accounted using fragility curves which are functions that indicate the probability of a structure, or a set of structures with similar characteristics, to exceed a specific damage state, given a level of ground shaking. Ideally, the derivation of these fragility curves is done by collecting sufficient information from damage of a large set of buildings from past earthquakes in the area of study; this however is difficult since enough post-earthquake quality data is typically non-existing and, therefore, analytical methodologies are implemented.

The social vulnerability sub-component is accounted by collecting specific observable demographic variables and processing them to characterize the capacity of communities to prepare for, respond to, and recover from damaging events.

Finally, all the components are implemented and statistically processed in a Web-Based Application which allows stakeholders in risk management to have a holistic notion of the overall risk of any particular seismic event.

3. HAZARD

3.1. Seismotectonic context of the Blida region

The seismicity around Blida can be considered as low to moderate and it is mainly the result of the compressional movement between the African and Euro-Asian plate.

The identification of 23 source zones to be used in the model is made following a new proposal developed for Northern Africa (Pelaez et al, 2018). The frequency-magnitude relationships of these sources are defined by processing the information of an existing seismic catalogue developed for events recorded in the Algerian context (Hamdache et al, 2010) which was extended and homogenized considering events until 2017.

3.2. Ground Motion Prediction Equations

Ground Motion Prediction Equations (GMPE) describe the amplitude of shaking as a function of earthquake magnitude, distance from the sources and site conditions among other possible variables. Since no GMPE has been specifically developed for Algeria, the models selected for evaluation are widely-accepted models that follow current state-of-the-art practices, especially in terms of near-fault wave propagation and magnitude scaling. Two GMPEs were selected, the NGA-Wst2 (Campbell & Bozorgnia, 2014) and the ASK14 (Abrahamson et al, 2014).

3.3. Seismic Hazard Results

The information indicated before was implemented in the OpenQuake (Silva et al, 2014) software using the classical approach to perform site-specific seismic hazard, building a logic tree structure to account for uncertainty.

The resulting seismic hazard curves for Blida are shown in Figure 1 in terms of PGA, and spectral acceleration, damped at 5%, for the oscillation periods of for 0.1, 0.2, 0.3, 0.5, 1.0 and 2.0s.

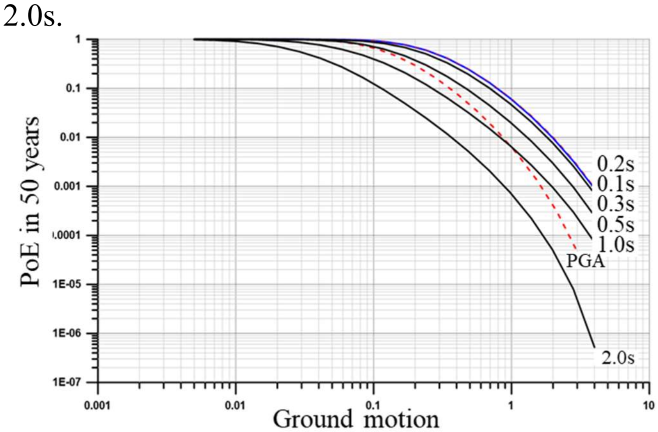

Figure 1: Seismic hazard curve for Blida in terms of PGA, and SA for 0.1, 0.2, 0.3, 0.5, 1.0 and 2.0s.

In addition, Figure 2 shows the Uniform Hazard Spectra calculated for Blida for the 475 year and 2475-year return periods.

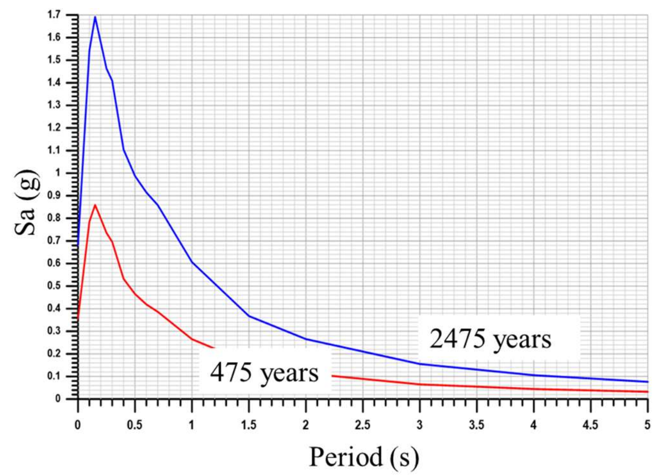

Figure 2: Uniform Seismic Hazard of Blida for a return period of 475 and 2475 years.

4. EXPOSURE

4.1. Building Exposure Model

Initially, given that in Algeria, there is no updated database that can be used to determine the amount and characteristics of the building inventory; census data along with expert opinion was used to approximate the building distribution and preliminarily gain insight on the typology of the inventory.

Later, a building taxonomy was defined by identifying different attributes which are both representative and have proven to approximately characterize the overall structural behaviour of structures. Such attributes are the material of construction, type of lateral load resisting system, year of construction and number of storeys.

The first and second attributes are organized in 4 categories: reinforced concrete moment resisting frames (RC MRF); dual reinforced concrete moment resisting frames and shear walls (RC MRF-SW); reinforced concrete shear walls (RC SW); and unreinforced masonry (UM).

The year of construction was associated with the availability of different versions of the Algerian seismic code, therefore being related to the seismic design level. Thus, buildings constructed before 1981 are categorized as pre-code (PC), while those built during the period ranging from 1981 to 1999 are termed medium-code (MC). The buildings constructed after 1999 are classified as post-code (C). Regarding the number of floors, three categories are considered herein: up to three storeys as low-rise (LR), between four and seven storeys as mid-rise (MR) and more than seven storeys as high-rise (HR).

Combining these classification parameters with the data from the Algerian building census survey of 2017, a municipality-based exposure model containing the number of buildings for each vulnerability class was created as shown in Figure 3. To verify this information and gather more specific data on individual assets (which was later used during the assessment of vulnerability), a smartphone application was created and distributed among the population, the spatial distribution of 2016 surveys collected with the use of this application is shown in Figure 4.

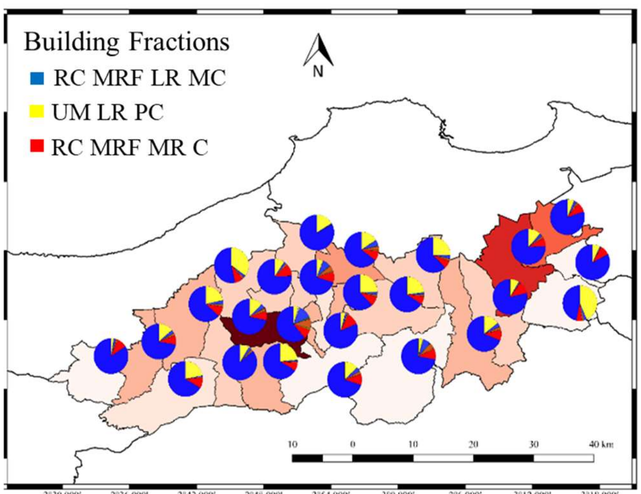

Figure 3: Municipality level exposure model for buildings in Blida.

4.2. Bridge Exposure Model

In the case of bridges, an exposure model was created primarily using an open-source online platform called OpenStreetMaps. This database contains metadata of the entire road network of Algeria, which was combined with a partial inventory obtained from Road Management Agency of Algeria, leading to the identification and spatial localization of 200 bridges in the city of Blida as shown in Figure 5.

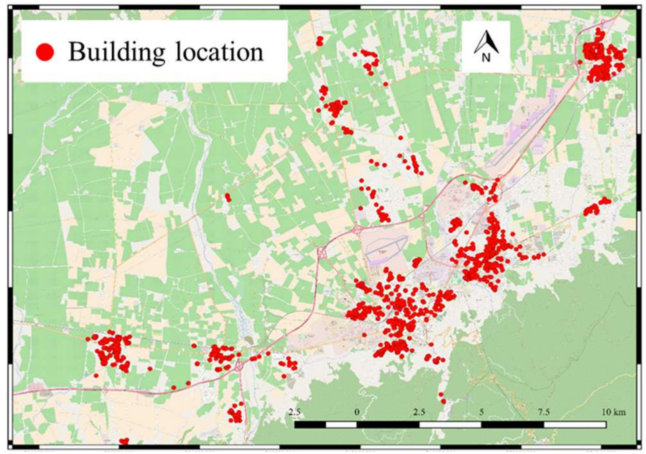

Figure 4: Spatial distribution of buildings surveyed with smartphone application.

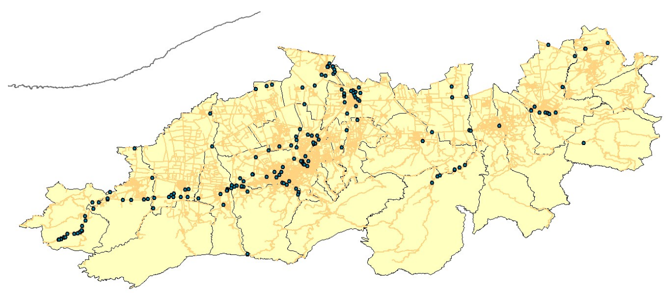

Figure 5: Spatial distribution of bridges identified in the city of Blida.

5. PHYSICAL VULNERABILITY

5.1. Building Vulnerability

The methodology defined for creating fragility curves for each building typology follows the procedure used by (Villar-Vega, et al., 2017) in which multiple references were consulted to obtain a wide set of capacity curves for each of the building typologies identified as part of the Algerian residential building inventory. The structural behavior of each typology is accounted for as the average capacity curve obtained from this previous step, which is then used to create a large number of synthetic equivalent single degree of freedom (SDOF) oscillators that represent the building-to-building variability of the entire inventory. As an example, the set of synthetic capacity curves generated for the MRF-LR-C taxonomy is shown in Figure 6.

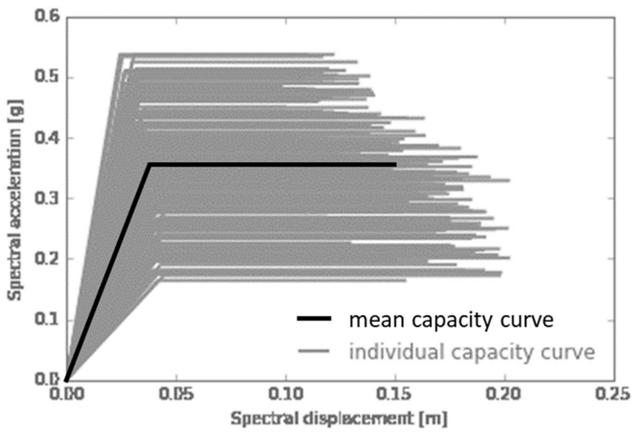

Figure 6: Set of 200 synthetic capacity curves generated to represent the MRF-LR-C typology.

Afterwards, a large set of ground motion records of increasing intensity is defined to represent the record-to-record variability, and both of these components are combined through a series of nonlinear time history analyses, leading to a distribution of damage per ground motion intensity level.

The earthquake record selection was performed taking advantage of the updated hazard model described previously. The Uniform Hazard Spectrum (UHS) for a return period of 475 years was used as a target spectrum for the selection of 40 compatible ground motion records, taken from the publicly available in the PEER (Pacific Earthquake Engineering Research) database using the Harmony Search algorithm implemented in the SelEQ (Macedo & Castro, 2017) platform, taking into consideration that the average spectrum of the complete set does not deviate from the target by more than 10% at any point and using filtering parameters, taken from a disaggregation analysis of the UHS for the 475-year return period case. The response spectra of each of the selected records is shown in Figure 7.

The complete set of 40 records was further scaled to represent different return periods, considering the relationship between PGA and return period taken from the hazard model, depending on the typology, at least 10 levels of return period ranging from 50 years to 50,000 years were considered.

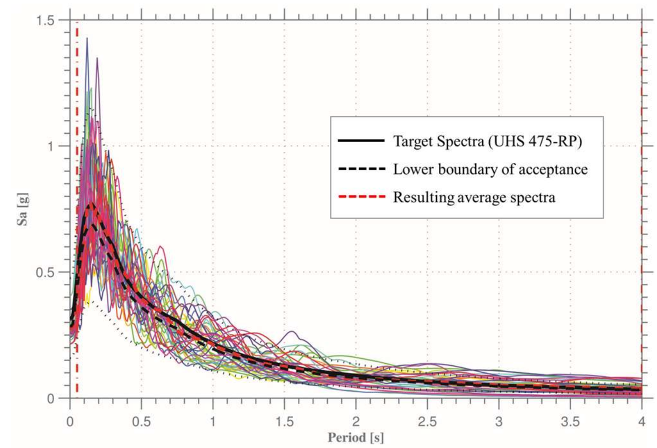

Figure 7: Response spectra for selected records scaled to match 475-year R.P. UHS for Blida.

The definition of the damage states was defined as proportions of the equivalent yielding and ultimate displacements reported by the capacity curve of each structure in the synthetic inventory. Four damage states were considered: slight, moderate, extensive and collapse. The slight damage state was defined by the attainment of 60% of the yield displacement and the moderate damage when the yielding displacement is exceeded. The threshold for extensive damage is defined as the mean between the yielding and the ultimate spectral displacement and collapse when the displacement of the system exceeds the 80% of the range between the yielding and ultimate displacements. This damage criteria leads to thresholds that are in agreement with past studies (Villar-Vega et al, 2017; Borzi et al, 2014).

The derivation of the fragility functions for each building class was performed through nonlinear time history analysis (NLTHA) of SDOF systems using the GEM Foundation's Risk Modeller's Toolkit (Silva et al, 2014). This module relies on the open-source software for nonlinear structural analysis OpenSEES (McKenna, 2011) to perform the NLTHA on the SDOF systems. The hysteresis model of each

SDOF was defined according to the associated capacity curve and using the "Pinching4 Material" model with structural degradation in both stiffness and strength. The dynamic analyses were performed with an elastic damping of 5% and using the standard pinching parameters from OpenSees, as there was not enough data available for a calibration process.

Nonlinear time-history analysis (NLTHA) was performed on each of the 200 single-degree of freedom (SDOF) models, using the set of 40 selected ground motions, which were scaled to 10 different levels of intensity, leading to a total of 80,000 analysis per each typology. Once each damage state probability is calculated for each ground motion record, a cumulative probability curve is fitted with a lognormal distribution to create the fragility functions for each typology. For this purpose, the lognormal statistical parameters are calculated using the least squares regression method, first determining which spectral acceleration period provides the pair of logarithmic mean ($\boldsymbol{\lambda}$) and logarithmic standard deviation ($\boldsymbol{\beta}$) that offer the best correlation with the observed damage distribution. These parameters are used in lognormal distribution function as follows:

$$P[ds|IM] = \Phi\left(\frac{\ln\left(\frac{IM}{\lambda}\right)}{\beta}\right) \quad (1)$$

This equation describes the probability of exceedance of a specific damage state (i.e., slight, moderate, extensive, collapse) based on a specific intensity measure of a ground motion. As an example, the resulting fragility function for the MRF-LR-C typology, for the structural period of best fit, along with the data scatter, is presented graphically in Figure 8.

5.2. Bridge Vulnerability

In the case of bridge vulnerability, given that very little information was made available on the structural detailing of characteristic bridges in Algeria by the managing public institutions, fragility curves from previous research were assigned to the assets that were identified as RC bridges (Kibboua et al, 2014) and masonry bridges (Tecchio et al, 2016) in the exposure model.

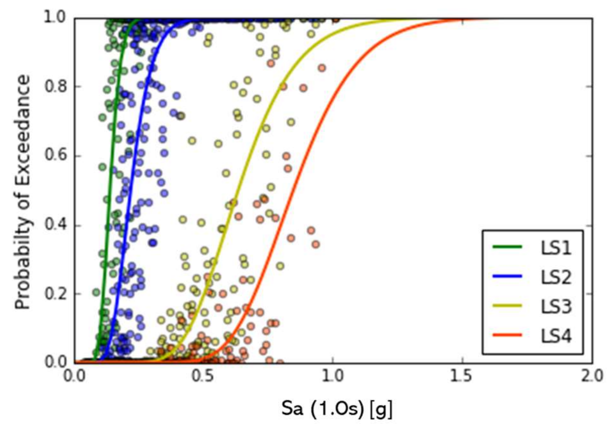

Figure 8: Fragility curves for RC-MRF-LR-C typology for Sa at 1.0 sec (best fit) [Slight (LS1), Moderate (LS2), Extensive (LS3) and Collapse (LS4)].

6. SOCIAL VULNERABILITY

One of the most known methods for accounting for social vulnerability is the composite vulnerability index score SoVI (Cutter, Boruff, & Shirley, 2003), in which a set of socio-economic independent variables are obtained from census data and separated into groups. Each of the underlying social dimensions is quantified by these factor scores (sub-indexes) which in turn are placed in an additive model to produce the composite social vulnerability index score.

The problem with the SoVI methodology, which is the case for Algeria, is that a great amount of data is required which is not always available for developing countries, and even when data is available, it is often incomplete, outdated, not available at the desired administrative level, or is collected at different points in time; rendering the results of the analysis less credible or difficult to interpret.

It is for these reasons that other methodologies have been developed which attempt to capture "real time" risk specific data, by making the use of a participatory engagement with the population in the form of a questionnaire; such is the case of the Resilience Performance

Scorecard Methodology RPS (Burton et al, 2017). The RPS is a multi-level and multiscale self-evaluation tool that empowers stakeholders to assess earthquake risk and resilience parameters based on qualitatively derived information.

After consideration, it was recognized that in the case of Algeria, neither methodology is ideal to accurately assess the social vulnerability of the Algerian population. The SoVI approach requires census information that for the case in question is not entirely available, and the RPS approach does not provide a measure of risk that can be directly integrated with the physical risk.

For this reason, a hybrid methodology was adopted, which combines both the previously described methodologies. All the available data from census that complies with the requirements of soundness and completeness, as well as all collected information from the questionnaires, will be processed together. To accomplish this, the answers of the questionnaire will be scored and each of the dimensions of the RPS will be treated as a group from the SoVI approach, obtaining a composite vulnerability index.

At the time of writing the current paper, the collection and processing of only three of the eight considered parameters (social dimensions) have been completed at the provincial level for the entire Algerian territory. The population, education and economy dimensions are here characterized by nine variables shown in Table 1 whose values are obtained from the 2008 census information.

Table 1: Parameter values.

Group	Indicator
POPULATION	*% Population < 18 years*
	% Population > 65 years
	% Female
	% Disabled
EDUCATION	*% Illiterate*
	% High school degree
	% University graduates
ECONOMY	*% of employment*
	% Female labor force participation

Before the construction of the indexes for each group, the raw data from census was standardized into comparable scales using percentages, after which the variables were transformed using a MIN-MAX rescaling scheme. Such as in previous projects (Burton & Silva, 2016), a method of aggregation was employed which represents the summation of equally weighted group scores.

The final composite score has values between zero and one (0 being the least socially vulnerable and 1 being the most vulnerable). An aggregation method using equal weights was applied due to the lack of theoretical justification for weighting one variable over another at this stage.

The results of the overall calculated vulnerability are shown in Figure 9 for the Northern Algeria region. It is important to note in this figure how some of the most recognizable provinces in the country show lower values of social vulnerability, which is due to hosting the least vulnerable age demographic and the highest percentage of active working population. Overall, the results lead to the preliminary conclusion that the least vulnerable province is the capital Alger, and the most vulnerable is Djelfa.

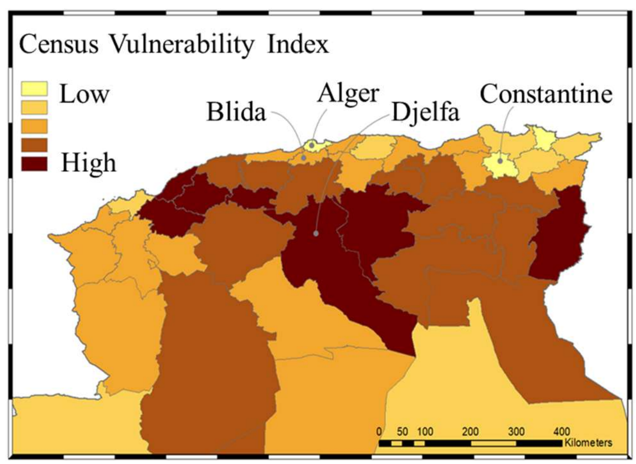

Figure 9: Spatial distribution of the preliminary results of the census-based social vulnerability assessment.

7. CONCLUSIONS

The current research lays the foundation of a framework for risk assessment in Algeria, by the development of a complete characterization of each of the seismic risk components for the case study of the city of Blida. This work is replicable to the rest of the country and expandable to the inclusion of different types of hazards. It is the intention of the authors that the scientific community of Algeria builds upon this work, to increase resilience of the country by generating tools to allow the successful implementation of disaster risk reduction practices.

8. ACKNOWLEDGMENTS

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