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Development of a seismic social vulnerability model for northern Algeria

Al Mouayed Bellah Nafeh [a], Hamoud Beldjoudi [b], A. Karim Yelles [b], Ricardo Monteiro [a,*]

[a] Scuola Universitaria Superiore IUSS Pavia, Italy
[b] Centre de Recherche en Astronomie Astrophysique et Géophysique, Algeria

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ABSTRACT

A common definition of seismic risk entails the quantification of three main elements: hazard, exposure of properties and societies, and corresponding vulnerability. When properly characterised, the vulnerability of a community or an asset is the easiest component to act upon, through governmental agencies and decentralised frameworks, when facing natural hazards. Algeria is a country with a relatively short history of seismic risk mitigation even though, in the past, the population suffered from many devastating earthquakes leading to large human and economic losses. Furthermore, until now, the actions taken to reduce such devastating effects have been of reduced impact. With this in mind, this paper investigates the social vulnerability and resilience level to natural hazards, with a specific focus on seismic risk, in the province of Blida, an important cultural and economic region in Northern Algeria. The evaluation is carried out through a hybrid methodology that puts together results from the well-known social vulnerability index or SoVI®, obtained from population data and national statistics, integrated with the Resilience Performance Scorecard (RPS) method, which qualitatively assesses the resilience of a population with reference to qualitative information gathered through public interest and participation. With such a methodology, this study aims to evaluate the societal factor and the impact on the population at risk through vulnerability mapping. The results allow identifying the areas and the social vulnerability dimensions requiring immediate addressing by regulatory and institutional frameworks that can increase preparedness levels, resource allocation, contingency planning, and efforts in raising public awareness. Following the use of census data and the participatory scheme, as well as a hybrid approach combining the two, it is seen that the province of Blida is characterised by medium levels of vulnerability. Following a simplified comparison, the SoVI approach results tend to underestimate the RPS ones. Such information will be useful to aid decision-makers and the exposed society itself to endure the effects of disastrous events.

1. Introduction

The overall seismic risk of a certain region requires the convolution of three main elements: hazard, exposure of properties and populations, and vulnerability, both physical and social, as per Equation (1).

$$Risk = Hazard \times Exposure \times Vulnerability \quad (1)$$

In the reduction of seismic risk, the vulnerability factor can significantly diminish the overall risk when characterised and quantified properly, when hazard and exposure are difficult to intervene on. On the other hand, the difficulty in quantifying the human dimensions within a hazard zone and the scarcity of readily available data (e.g. from the census) usually disregard the social effects when performing a seismic risk assessment. The quantification of such human dimension (through census data) within a zone particularly prone to a specific hazard aids decision-makers and the exposed community itself to handle the consequences of a catastrophic event. To this end, social vulnerability assessment evaluates the distinct repercussions that different communities, whether exposed to similar or distinct societal conditions, may demonstrate under uniform levels of hazard. Socio-economic characteristics related to community preparedness, response, and recovery to a disastrous event are therefore investigated and included in the assessment [1].

Multivariate analysis (i.e. assessment considering several different variables) for the development and quantification of social resilience and vulnerability assessment indices has been broadly performed since the early 1990s. For example, the research studies by Refs. [2–10] provided a strong setting for the development of a social vulnerability index (SoVI®) and its implications in understanding the necessities for improved community resilience. The SoVI® is an indicator-based

* Corresponding author.
E-mail address: ricardo.monteiro@iusspavia.it (R. Monteiro).

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approach that refers to quantifying the social vulnerability of a community and subsequently aids decision-makers in assessing the resilience level of said community when confronted by external stresses, such as natural or human-induced hazards, on human health and activities. The aforementioned index is obtained through the identification of numerous social indicators within general areas of interest or social dimension (e.g. the use of unemployment rate under Economy), that are, by definition, readily available from census data. Those indicators are post-processed, and a score is attributed to each of them. SoVI® uses census variables to help local officials identify communities that may need or lack support in preparing for upcoming hazards or recovering from disasters. When addressed properly and effectively, social vulnerability decreases which reciprocate in reducing human distress and reduces expenditure for public assistance and services to be allocated after the occurrence of an event. Furthermore, other approaches such as the Resilience Performance Scorecard RPS [11] have emerged also as an attempt to identify and fill gaps in the quantification of indicators that may not be publicly available, hence hamper the readiness of the SoVI® approach, through the design of targeted questionnaires. The methodology provides a multi-scale self-evaluation tool that can apprehend the fundamental practical and policy-making fields for urban resilience enhancement through qualitatively derived information.

Several studies have been conducted in the framework of social vulnerability quantification of cities and vulnerable populations [1, 12–21]. These were all pilot case-studies that established prototypes for social vulnerability characterisation and resilience metrics quantifications while incorporating one of the two previously introduced approaches (i.e. classic social vulnerability index SoVI® and Resilience Performance Scorecard RPS) or employing both simultaneously with RPS being included as a component for the computation of SoVI®.

A methodology has been outlined to quantify these effects objectively, merging concepts from the two previously mentioned, well-known techniques. Specifically, the methodology is based on the calculation of a composite index, using a comparative analysis of census-based data through a social vulnerability index (SoVI®) [9], integrated with the results from public engagement of the targeted audience or population, through the use of a self-assessing survey or questionnaire, as per the Resilience Performance Scorecard Method prescribed in Ref. [11]. This study, therefore, presents the computation of a hybrid social vulnerability index and the assignment of an average vulnerability score for different districts of a case-study region, representative of the Northern Algerian territory, reverting to the chosen indicators and the results of the questionnaire data. The computation of a comparative resilience (herein seen, for simplicity, as the inverse of social vulnerability) of a group due to socio-economic parameters is conducted, through distinguishing conditions that make people or properties susceptible to severe natural events. By doing so, this study aims to employ and critically review both techniques in the calculation of an overall vulnerability score for the case-study region of Blida, a densely populated province in Algeria whose constituents are convenient for the employment of the hybrid approach described herein.

2. Methodologies for social vulnerability assessment

2.1. Social vulnerability index (SoVI®)

The social vulnerability index (SoVI®) method was primarily proposed in Ref. [22] with the aim of reprioritising post-event emergency management systems. This method facilitated the understanding that the vulnerability of communities to natural hazards is not mainly attributed to the vicinity to the source of peril or the strength of the event (i.e. hazard) nor to the physical vulnerability of the exposed assets alone (i.e. exposure and fragility), but also equivalently affected by the social fabric of the afflicted community. The social vulnerability index assesses the level of susceptibility of a case study population to a hazardous event through a set of independent socio-economic groups that are then sub-categorised into indicators. Decision-makers can subsequently opt to utilize other composite indexes to assess the resilience of a community under scrutiny as outlined in Ref. [23]. The indicators for social vulnerability assessment are collected at the desired geopolitical level from census data. Subsequently, such indicators are normalised and processed using statistical tools (i.e. factor analysis) to establish the impact of each in its corresponding group, measured in the form of constants or factor loadings. The sum-product of each indicator for every desired geographical level and the determined factor loading within a group is termed the factor score [22]. The composite social vulnerability index (SoVI®) is thus obtained through the characterisation of every relevant social dimension (e.g. population, economy, health, etc.) quantified with factor scores (sub-indices), and subsequently assigned in an additive model [9]. SoVI® is a relative metric that provides scores based on the geopolitical scale of reference chosen for the analysis. There are two approaches to conducting and classifying social vulnerability assessment, namely deductive and inductive. Respectively, the former relies on the selection of a narrow array of variables, as done by Ref. [22,24,25] and others, whereas the latter uses a structured and comprehensive social vulnerability evaluation framework with all conceivable variants considered at a given time (i.e. the use of indicators most relevant and available at the time of analysis). Recent developments in the assessment of social vulnerability are more attentive to the inductive method due to the readily available large number of census data (e.g. Ref. [9,26]). While this work applies the inductive approach, a comparative study between both approaches is outlined in Ref. [27].

2.2. Resilience performance scorecard (RPS) approach

The Resilience Performance Scorecard Methodology (RPS) is a multi-scale assessment and participatory tool [11], which enables stakeholders to evaluate seismic risk and resilience parameters based on qualitative evidence. RPS engages the exposed group or communities, leading to an increase of awareness and identification of key gaps at the community and institutional level within the boundary level. The implementation of the RPS approach foresees target surveys, carried out with dedicated questionnaires to address the reality of the society under evaluation and applied to both community members and local administration or institutional stakeholders in the risk management field. The key areas addressed by the survey are highlighted in Ref. [28] and includes social capacity, awareness and advocacy, legal and institutional arrangements, planning and regulation, critical infrastructure and services, and emergency preparedness and response.

2.3. Merging SoVI® and RPS: composite social vulnerability index

To assess the social vulnerability of the Northern Algerian population, none of the two methodologies alone was considered ideal. The SoVI® approach necessitates census information, which was not entirely available, as happens many times in developing countries. In contrast, the RPS approach does not deliver a quantification of risk that can be directly associated with physical risk. A composite methodology was thus adopted, combining both methodologies with the available census data, and collected information from the questionnaires. The dimensions of the RPS were scored and treated as an additional dimension to the SoVI® framework, thus obtaining a composite vulnerability index. The overall methodology for incorporating the population's feedback to the RPS approach into the SoVI® approach, using the available census data, is summarised in Fig. 1. The combination of social and physical vulnerability models can be subsequently performed, among other approaches, by crossing identified vulnerability classes in terms of population and damageable assets such as buildings. The latter can be applied by adopting the same scale to both physical and social vulnerabilities, employing e.g. a min-max scheme, and crossing both elements to form a unique "vulnerability" matrix. Such application is referred to as

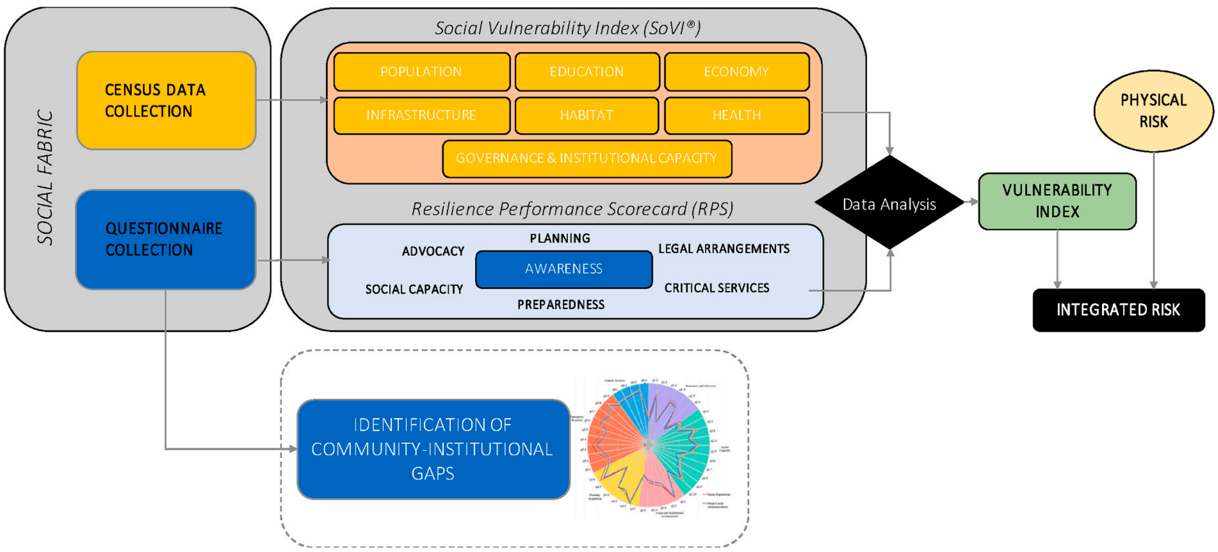

Fig. 1. Schematic representation of the methodology for social vulnerability assessment adopted for social vulnerability assessment of Blida, Algeria.

integrated risk model, particularly useful for decision-makers and civil protection agencies when identifying locations with vulnerable population and assets.

3. Social vulnerability assessment results for northern Algeria

The procedure for seismic social vulnerability assessment is defined as the social equivalent to structural risk evaluation for seismic hazard. Seismic social vulnerability assessment aids policy-makers, governmental institutions or the general public in understanding the differential experience of communities to an earthquake event even when exposed to similar levels of ground shaking. The initial step towards quantifying the social vulnerability index is to pin-down adequate contextual conditions to characterise the population of interest given a case-study region. These conditions are based on the case study area's social composition. The latter comprises existing socio-economic features related to the overall capacity of populations to themes such as preparedness, response and recovery during damaging events [22].

Within this context, there is extensive research focused on those factors that directly correlate with the impact of hazard events on populations. These characteristics include age, gender, access to resources such as education, healthcare, and income distribution [9, 29–31]. Moreover, such characteristics involve the distribution of health-related facilities, and elements of the urban/rural environment such as the density of habitat and infrastructure and finally, governance and institutional capacity [9]. These societal characteristics are quantified and aggregated into indicators derived from observational facts or census data whose aim is to convey the reality of multifaceted circumstances [32]. Therefore, SoVI® is a prevailing instrument as it incorporates complexity and provides quantitative metrics to associate and distinguish between societies, resiliencies and progress-in-the-making of a particular group as well as it is a relatively easy tool for non-experts to understand [33].

3.1. Case-study region: the province of Blida

Blida is a province in northern Algeria that includes 10 districts and 25 municipalities, as illustrated in Fig. 2. The province possesses a high percentage of buildings designed with no consideration to seismic codes, along with poor urban planning, rendering it particularly vulnerable to natural hazards. Additionally, the region of northern Algeria is characterised by high seismicity, as demonstrated by past earthquakes with devastating impacts, such as the "El-Asnam" event of 1980 ($M_w = 7.1$) and the "Boumerdés" event of 2003 ($M_w = 6.8$). Blida and Oran, two of

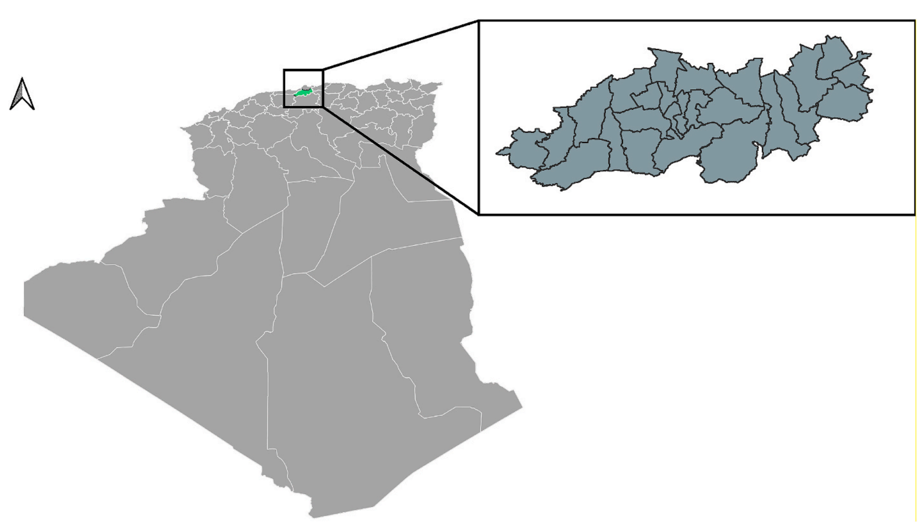

Fig. 2. Province of Blida and the corresponding municipalities borders.

the most seismically-prone cities in the region, present peak ground accelerations, for a return period of 500 years, of, respectively, 0.493 g and 0.361 g. Further information on the regional hazard can be found in Ref. [34–38]. The identification of the seismic prone province of Blida was carried out within the activities of the EU-funded project ITERATE (Improved tools for Disaster Risk Mitigation in Algeria, www.iterate-eu.org), which focused on the development of an integrated seismic risk model in developing countries, specifically, Algeria [39–42]. Demographically, the population of Blida is about 3% of the total Algerian population with an equal ratio of men and women (51% and 49% respectively). The province of Blida is a considerably young population with just under 40% of its inhabitants under the age of 18 and 55% between the ages of 18 and 65. Blida is considered to be representative of typical Algerian construction practice and diversity in population, whose social vulnerability should be characterised by a proper model. In addition to the quantification of integrated seismic risk, such a model is also useful to engage stakeholders and disaster-mitigation officials in establishing a prioritisation scheme for pre-event preparedness and post-event aid through the identification of vulnerable communities.

3.2. Social vulnerability index (SoVI®)

The computation of the SoVI® for the province of Blida employs a set of 33 census-based indicators, collected on the provincial administrative levels, grouped into seven main groups, namely: Population, Education, Economy, Health, Infrastructure, Habitat, Governance and Institutional Capacity. The choice for these variables was based on their relevance in portraying resilience of the considered community and the available literature. Also, the selection was based on the availability of the aforementioned indicators in the national statistics (ONS, National Office of Statistics [43]) and census data. Before the definition of any index, raw census data was collected, standardised, processed and transformed to fit a comparable scale by employing a MIN-MAX normalisation procedure (where 0 and 1 denote respectively the and most socially vulnerable), as indicated in Equation (2), where $x^t_{qu}$is the value of the indicator q for listing unit u, at time t; $\min_u(x^t_{qu})$, $\max_u(x^t_{qu})$ are, respectively, the minimum and maximum values of the indicator q; and I^t_{qu} is the index score transformed subsequently to a value ranging from 0 to 5 (with 0 being the least vulnerable and 5 the most vulnerable). In symbols:

$$I^t_{qu} = \frac{x^t_{qu} - \min_u\left(x^{t_0}_q\right)}{\max_u\left(x^{t_0}_q\right) - \min_u\left(x^{t_0}_q\right)} \tag{2}$$

The variables for which low values were attributed to high levels of vulnerability, the rescaling procedure was employed using the inverse of the observed value. Moreover, unavailable datasets were interpolated using a “reference country” approach, i.e. when the indicator value was known only for the province of Blida, without any information regarding other provinces, that value was normalised with reference to the range of that indicator in countries of similar geographical or socio-economic conditions). Other datasets were also derived from “proxy” available indicators, whose correlation with the unknown indicator is high ($\rho >$ 0.5 or $\rho < -0.5$). The list of indicators, along with their correspondent sub-indices, are listed in Table 1.

Table 1 illustrates the indicators used in this study along with cardinality, i.e. effect of increasing (+) or decreasing (−) the social vulnerability of a given population. The different indicators, together with their sub-indices, are described in further detail in the following sections.

3.2.1. Population

The population indicator uses demographic characteristics to predict the vulnerability of populations to threat from natural hazards and to recover from disastrous events when they occur. Demographic classes that are regarded as the most vulnerable typically feature elders (over 65 years of age), young persons (under 18 years of age), individuals with disabilities, foreign nationals, refugees. Additionally, it is generally assumed that, due to sector-specific employment, relatively lower salaries and family care responsibility, women are more vulnerable during recovery than men [9]. The selected indicators of the population-related vulnerability (in Northern Algeria), along with their corresponding scores, are listed in Table 2. Variables for which data was not readily available were substituted with proxy variables obtained at a national scale.

Table 1
Indicators used in SoVI analysis.

Group	SoVI No.	Social Vulnerability Indicator	Cardinality
Population	1	% Population <18 years	+
	2	% Population >65 years	+
	3	% Disabled population	+
	4	% Refugees	+
	5	% Population of foreign nationalities	+
Education	6	% Illiterate population	+
	7	% Without elementary education	+
	8	% Without high school education	+
	9	% With a high-school degree	–
	10	% University graduates	–
Economy	11	Unemployment rate	+
	12	% Labour force in the secondary sector	+
	13	% Labour force in the service sector	+
	14	Female labour force participation	+
	15	Average monthly income	–
	16	% Poverty	+
Health	17	No. of Hospitals	–
	18	No. of Hospital Beds	–
	19	No. of Doctors	–
	20	Crude Birth Rate	+
	21	Crude Death Rate	–
	22	Life expectancy	–
	23	% Basic health system coverage	–
Infrastructure	24	Road network coverage	–
	25	% Population without access to water	+
	26	% Population without access to electricity	+
	27	No. of vehicles (per person)	–
Habitat	28	Population density (pp/km^2)	+
	29	Housing density (pp/house)	+
	30	Urban density (no. of buildings/km^2)	+
	31	No. of households	+
Governance & Institutional Capacity	32	Crime rate	+
	33	Abstention rate from local elections	+

3.2.2. Education

The education factor is determined by assuming that high-level

Table 2
Population-related indicators for SoVI analysis and resulting vulnerability score.

Population Indicators	Percentage	Vulnerability Score
<18 Years	37.92%	**1.90**
>65 Years	4.92%	**0.25**
Disabled	5.15%	**0.26**
Refugees	0.22%	**0.01**
Immigrants and Minorities	0.66%	**0.03**
	Total	**2.56**

education is linked to greater earnings over a lifetime and easier access to information. In the case of disasters and conflicts, a strong correlation exists between the level of education received or achieved and a community's ability to cope with such events, as outlined by UNESCO and UNICEF [44]. Moreover, it is assumed that populations with poor education do not have access to warning information and recovery aid after a disaster. Thus, a better-informed society with a higher level of preparedness is achieved through continuous exchange with highly educated levels of the community. Selected indicators, chosen to be most representative, along with the vulnerability score attributed to education, are listed in Table 3.

3.2.3. Economy

The financial well-being of a population affects significantly its ability to cope with losses and improve resilience to hazards and their consequences. Wealth allows societies to absorb and recuperate from losses more quickly due to insurance, social safety and welfare, and relief programs through government assistance. Income indicators are complemented with the type of employment that is present in a community, since some lines of labour may be compromised after a disaster. For example, low-skilled service workers (e.g. gardening, housekeeping or childcare) may be affected, as disposable income diminishes and the need for services decreases. The selected indicators, assumed to be representative of the economic-related vulnerability, are listed in Table 4.

3.2.4. Health

Healthcare services and providers, such as the medical corps (physicians, nurses, etc.), clinical care facilities (e.g. hospitals), are fundamental in post-event relief. Shortage of medical facilities will compromise the immediate response and long-term disaster recovery. The capacities and personnel of healthcare facilities, the life expectancy of the population, and the coverage of basic social security services control the overall quality of healthcare services. Table 5 summarises the health-related indicators for the social vulnerability of Blida.

3.2.5. Infrastructure

The access to utilities and amenities, such as piped water and electricity, and the availability of multiple road access lines improve the post-disaster response, and therefore, reduce vulnerability. The infrastructure indicator category is summarised in Table 6 along with the respective vulnerability scores and their average.

3.2.6. Habitat

The habitat in terms of population and built environment density can prove either beneficial or detrimental in the event of a disaster. Dense urban areas require more resources, while often the process of evacuation may be more difficult. Additionally, residential ownership is an indicator of financial stability and of families well rooted in the locality. The aforementioned indicators are illustrated in Table 7.

3.2.7. Governance and institutional capacity

This category captures the ability of communities to engage in organisational connections, to reduce risk through mitigation and preparation. Indicators such as abstention rate in elections are used as a measure for community involvement, at least indirectly, in risk reduction. Crime rate, on the other hand, is assumed to be an indicator of the capacity of communities to shelter social and organisational systems. The assumed indicators are summarised in Table 8.

Table 3
Education-related indicators for SoVI analysis, their respective scores (0 least vulnerable, 5 most vulnerable) and total vulnerability score.

Education Indicators	Percentage	Score	Vulnerability Score
Illiterate	17.20%	5	**0.85**
No elementary education	16.00%	3.75	**0.49**
No high school education	35.00%	2.5	**1.52**
High school education	24.20%	1.25	**0.71**
Graduated	7.60%	0	**0.00**
		Total	**3.57**

Table 4
Economy-related indicators for SoVI analysis and vulnerability score.

Economy Indicators	Value	MIN	MAX	Vulnerability Score
Unemployment	2.44%	0.20%	3.20%	**1.25**
Women Labour Force	13.30%	3.00%	52.00%	**3.95**
Average Monthly Income	345 USD	264.33	937.16	**1.95**
Poverty	6.79%	6.20%	28.00%	**0.70**
% Labour Force in Service Industries	30.37%	4.00%	95.7%	**1.44**
% Labour Force in Secondary Sectors	16.07%	2.30%	62.8%	**1.14**
	Total (Average)			**1.83**

Table 5
Health-related indicators for SoVI analysis and vulnerability score.

Health Indicators	Value	MIN	MAX	Vulnerability Score
N. of Hospitals (per 1000 population)	0.067	8	3820	**4.81**
N. of Beds (per 1000 population)	2.61	381	3274	**2.86**
N. of Doctors (per 1000 population)	1.49	130	272	**0.74**
Crude Birth Rate (per 1000 population)	24.44	1487	96383	**1.52**
Crude Death Rate (per 1000 population)	3.87	26	17013	**1.41**
Life Expectancy at Birth	67.3 years	66.2	77.2	**4.50**
% with Basic Health Insurance	100%	–	–	**0.00**
	Total (Average)			**2.26**

Table 6
Infrastructure-related indicators for SoVI analysis and vulnerability score.

Infrastructure Indicators	Value	MIN	MAX	Vulnerability Score
Road Network (in km/km^2)	0.85	684	6408	**0.50**
% Population without Water	4.84%	31.7%	100%	**0.35**
% Population without Electricity	0.18%	7.6%	100%	**0.01**
Vehicles (per person)	0.12	0	2	**4.61**
	Total (Average)			**1.19**

Table 7
Habitat-related indicators for SoVI analysis and vulnerability score.

Habitat Indicators	Value	MIN	MAX	Vulnerability Score
Density (pp/km^2)	636.00	0.20	3666.4	**0.87**
Housing Density (pp/house)	6.70	5.30	8.00	**2.59**
Urban Density (No. buildings/km^2)	3.77	10.00	19408	**2.05**
Number of Households (per province population)	0.15	9273	514744	**1.01**
	Total (Average)			**1.63**

3.2.8. Summary remarks

The results of the previous sections (3.2.1 to 3.2.7) are summarised and illustrated in Fig. 3. The average un-weighted social vulnerability score is calculated to be 2.19 on a scale of 0–5. Among the indicators

Table 8
Governance and institutional capacity-related indicators for SoVI analysis and vulnerability score.

Governance and Institutional Capacity Indicators	Value	MIN	MAX	Vulnerability Score
Crime Rate (over 120)	47.8	**3.0**	**63.0**	**1.99**
Abstention Rate	51.88%	**26.0%**	**79.0%**	**2.59**
	Total (Average)			**2.29**

listed above, the economic, habitat and infrastructure sectors seem to perform better, when compared to the other sectors. Health and governance score around the average value, as expected considering the sufficient health coverage system and the mediocre involvement of the population in political affairs. The education and population dimensions demonstrated the highest vulnerability scores due to reasons related to the illiteracy rate (17.2%), achieved level of education (population without elementary and secondary education level respectively at 16% and 35%) and considerable amount of vulnerable population groups, listed at 48.8% of the total population. The economic dimension is kept at low vulnerability levels for many relevant reasons witnessed from census data (i.e. low percentage of women labour force, small percentage of poverty and generally low unemployment rate). Habitat and infrastructure domains also provided low levels of vulnerability due to low urban and population densities and the provision of essential services (i.e. gas, electricity and water) to most of the inhabitants. The information reflected through Fig. 3 quantifies the human dimension within a natural hazard-prone zone and aims thus to highlight the immediate need for governmental and institutional frameworks that can contribute to decreasing the susceptibility levels of being affected given a hazardous event. This information should then, at a preliminary level, allow governmental decision-makers to identify the fields where to invest the most.

3.3. Resilience performance scorecard approach

As previously highlighted, the RPS approach aims to capture significant functional and governmental areas of opportunity to improve urban resilience with the involvement of local government entities (i.e. decision-makers). To this end, an interaction with stakeholders is required for the design of the indicators, targets (respectively questions and answers) and the participatory scheme altogether. Accordingly, a questionnaire (Appendix A) was organised in six sections representing different resilience dimensions, in agreement with the strategic goals of the Sendai Framework of the United Nations Office for Disaster Risk Reduction [44]. The results were processed in terms of location and frequency (i.e. participations given location), then disaggregated based

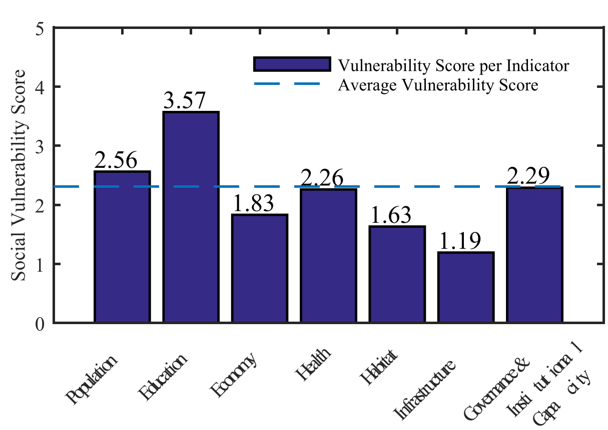

Fig. 3. Indicator scores and the average aggregated social vulnerability score.

on dimension (see Table 9) to understand the differences in perception, and then grouped into one single indicator, awareness, which was subsequently integrated within the classic SoVI® approach, thus leading to the hybrid approach mentioned in section 2.3. The dimensions of the questionnaires were previously conceived in Refs. [10,45], employed in previous studies such as [18,46] and adopted herein. However, each of the questions and eligible answers were tailored to the Northern Algerian context and has been developed and reviewed in cooperation with local experts to assure that the overall questionnaire captured the reality of the target communities. Table 9 summarises the dimensions and general themes covered by the questionnaire.

An additional indicator "Awareness" was added to the list of indices figuring in the classical approach for a better understanding of the awareness of the population towards risk within a comprehensive analysis. Such indicator resulted from the feedback of the general public, academics and scholars, and those employed in public sectors, quantifying the knowledge on the topics illustrated in Table 9. This indicator is based on the outcome of the participatory forms disseminated to engage the population when carrying out the evaluation of social vulnerability and employing the RPS approach [17,18]. The outputs of the SoVI® and the RPS approaches were subsequently integrated, as the level of awareness is considered crucial in social vulnerability studies [18].

Following the outcome of the survey, in terms of number of collected questionnaires, shown in Fig. 4, the Northern Algerian province of Blida was accordingly sub-divided and disaggregated in two representative geographical areas, as in Fig. 4, considering the follow factors: survey participants (83), of which have declared they are residents of the Blida province (67), of which are disaggregated into residents of the Blida municipality (29) and adjacent municipalities (38) and illustrated in Fig. 4 above.

Analysing the results of the RPS approach in detail, Fig. 5 illustrates the average scores obtained with the questionnaires, in terms of questions and general dimensions after disaggregating the province of Blida in two geographical sectors (i.e. main centre and neighbouring municipalities grouped all together). The choice for these two sectors was made to address the bias related to the high and low number of participants, respectively, from the Blida municipality and the surrounding municipalities. The data in Fig. 5 aids decision-makers and governmental bodies in understanding the reality of what is perceived by the inhabitants of Blida (i.e. scholars, public sector workers, citizens, amongst others) on what regards awareness levels, preparedness, efficiency of existing mechanisms and policies, and, generally, the level of resilience of critical services. A large discrepancy between the two

Table 9
RPS indicators, dimensions and grading scheme.

Dimensions	General questions	Grading scheme
Awareness & Advocacy	Knowledge of earthquake disaster risk and level of awareness.	1 = Almost none (little or no awareness) 2 = Low (awareness of needs)
Social capacity	Population capability in efficient preparedness, response and recovery from a damaging earthquake.	3 = Moderate (engagement and commitment)
Legal and institutional arrangements	Efficiency of mechanisms advocating earthquake risk reduction in nearby quarters.	4 = High (full integration) 5 = Not applicable (problem with the question or the target)
Planning, regulation and mainstreaming risk mitigation	Alleged level of commitment and mainstreaming of DRR through regulatory planning tools.	
Emergency Preparedness, Response and Recovery	Level of efficiency of disaster management including response and recovery mechanisms.	
Critical Services and Public Infrastructure Resiliency	Resilience of critical services to disasters.	

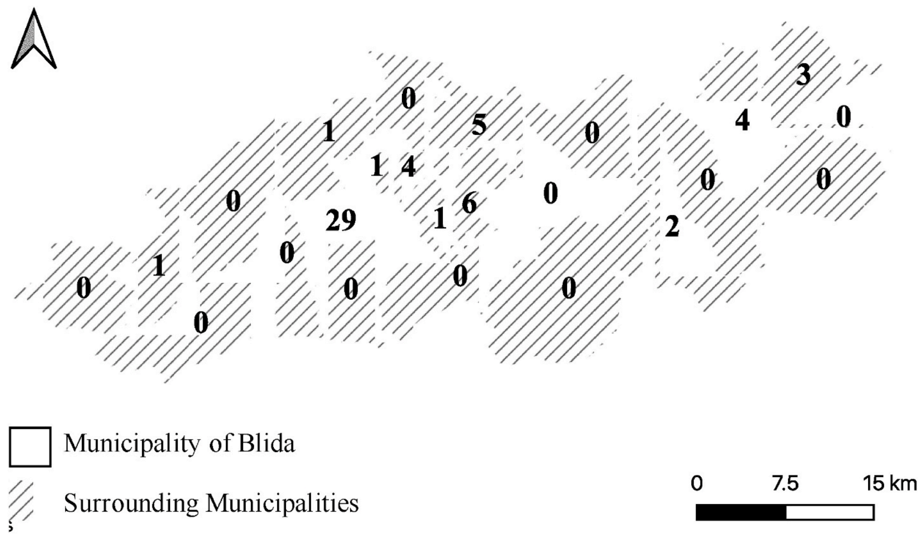

Fig. 4. The province of Blida and the assumed geographical setting with questionnaire participation number and location by municipality.

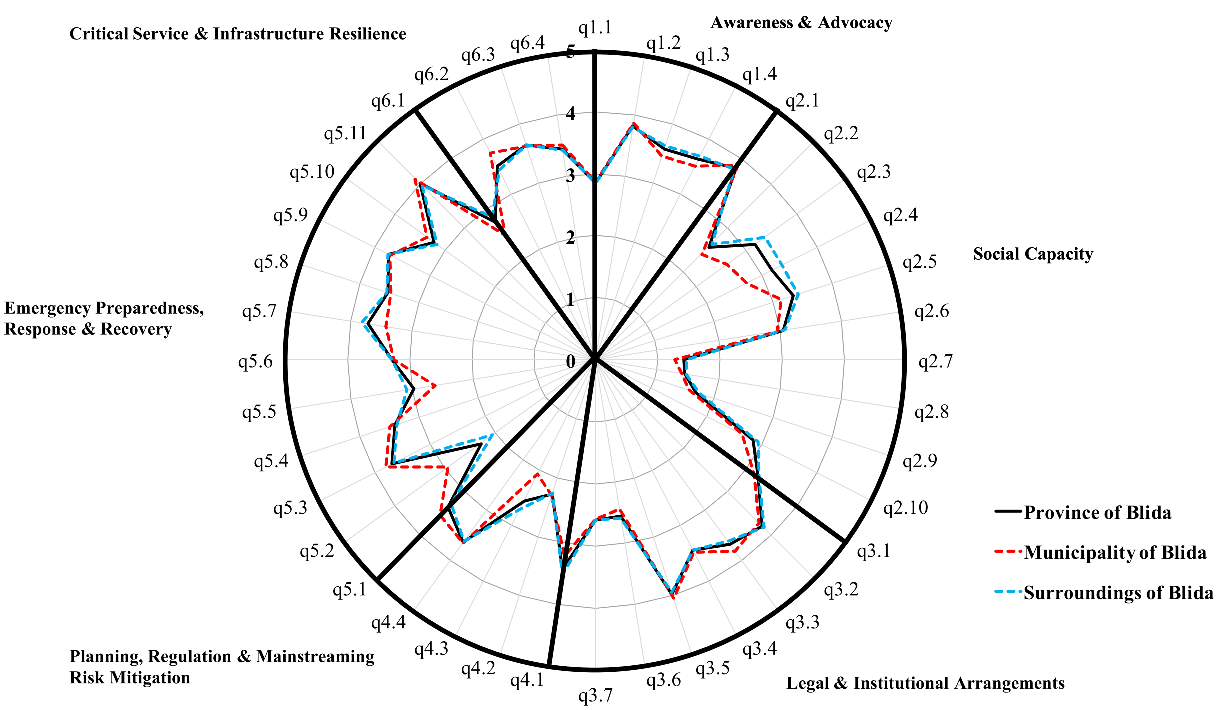

Fig. 5. Mean scores for RPS questions and dimensions for the province of Blida (before disaggregation), municipality of Blida and the surrounding municipalities (after disaggregation).

defined geographical sectors is observed in the answers provided to question 2.3, regarding the level of social integration of minorities. This can be related to the low percentage of minorities residing in Algeria, in general, and in the province of Blida, in particular, as well as to the low exposure level to foreign nationals/minorities in surrounding municipalities. These circumstances render the scores for question 2.3 likely less attenable and harder to interpret. A similar relative trend is found for question 2.4, which is related to the participation of the residents in the decision-making. The score for central Blida is higher with respect to the surroundings, which was expected, given that the more urban population tends to be more participative and included. It can be clearly observed that the participants' unawareness to social capacity themes is significant, reflected by the low scores given by questions 2.7, 2.8 and 2.9 of the survey on social capacity. Feedback also showed that a large sample of the population expressed low awareness to matters of access to gas and electricity (i.e. access to essential amenities) in their respective districts. For what concerns legal and institutional arrangements, the population sample showed low confidence in their local administrative entity (i.e. civil protection agency) in the case of any hazardous event, such as an earthquake, as indicated by the score of question 3.6. Regarding the planning, regulation and mainstreaming of risk mitigation, survey takers were mostly unaware whether seismic provisions in building construction codes were enforced in the city or whether earthquake insurance was available or utilised in the city by residents and business owners. This level of unawareness was detected through questions 4.2 and 4.3. The adjacent municipalities to the main Blida centre showed obliviousness on what regards the availability of a close local centre for implementing and coordinating emergency response and management (e.g. red crescent offices, civil defence or hospitals) This generally suggests that these institutions aiding in emergency preparedness, response and recovery are either centralised in the main city of Blida and quasi-absent on the outskirts, given the scores of the main city in comparison with the surroundings on question 5.2. Otherwise, it may indicate that the inhabitants are genuinely unacquainted with such facts. Based on the questionnaires, the local administration might consider developing plans and strategies to address low levels of awareness among the population.

The results of the questionnaires are also summarised in Fig. 6, which illustrates the performance of the RPS approach in detecting differences in the levels of perception of the local inhabitants. Fig. 6 (a) and (b) present the contribution of the RPS themes and dimensions to the "Awareness" indicator, following the post-processing of the feedback to the questionnaires of the Blida province and after the disaggregation of the province explained herein respectively. The scores of individual questions pertaining to a given theme (outlined in the questionnaire in Appendix A) were processed according to the grading scheme highlighted in Table 9. Subsequently, the score of each theme was obtained by averaging the individual results of each question, as shown in Fig. 5. Then, the scores of each theme were aggregated into the "Awareness" indicator by averaging the score of each social dimension (as per Table 9) for the Blida province and the defined geographical zones in the study (i.e. Municipality of Blida and its surroundings). Furthermore, Fig. 6b shows no discrepancy in the feedback provided during the application of the RPS approach, meaning that there is no large variation in the answers provided between the two geographical zones. This would influence uniformly the results obtained when integrating the two methodologies. "Generally, before and after the disaggregation of the Blida province, on average, the "social capacity and planning", "regulation and mainstreaming risk mitigation" dimensions indicated low levels of vulnerability when compared to other dimensions. On the other hand, themes as "awareness, legal and institutional arrangements" and "emergency preparedness, response and recovery" showed inadequate values reflected by higher vulnerability values." Governmental institutions and civil protection agencies should therefore mobilise towards new policies to enforce better and improved mechanisms for response and recovery, as well as informing and keeping the general public involved in enhancing their capacity of efficiently preparing and responding to natural hazard events.

4. Integrated vulnerability assessment: hybrid approach

4.1. Average social vulnerability score

Following the processing of both the initially proposed social vulnerability index and the RPS response, the total score has been calculated and defined within a range from 0 to 5, considering different weights for each indicator. These weights were defined in the study herein by considering different factors, such as completeness of data, significance of the indicator or relevance. Concerning indicators whose data was not adequately illustrative of the actual context such as Infrastructure and Institutional capacity, a low weight value was assigned. Moreover, the "Awareness" dimension was assigned a lower weight given that the classical SoVI® approach does not foresee the inclusion of such indicator and also considering the sample size (83 participants) that was possible to obtain. Weights were then equally assigned amongst the remaining indicators. Ideally, equal weights would be assigned to each indictor as is typically foreseen in applications of the SoVI approach [33]. However, in this context, lower weights were assigned to indicators whose data was not sufficiently representative (i.e. infrastructure and governance – 5%). Additionally, the resultant of the RPS approach was also given a lower weight (also 5%) given that it is not typically integrated within the SoVI framework. The remaining indicators were assigned equal weights. Given the aforementioned reasoning, the assigned weights are presented in Table 10. Similar justification is highlighted in Ref. [17,19]. Moreover, the output

Table 10
Vulnerability score per individual indicator and average score for the province of Blida.

Indicator	Vulnerability Score (un-weighted)	Weight (%)	Vulnerability Score (weighted)
Population	2.56	17	**2.35**
Education	3.57	17	
Economy	1.83	17	
Health	2.26	17	
Habitat	1.63	17	
Infrastructure	1.19	5	
Governance and Institutional Capacity	2.29	5	
Awareness	3.14	5	
Average Vulnerability Score (Blida)	**2.31**		

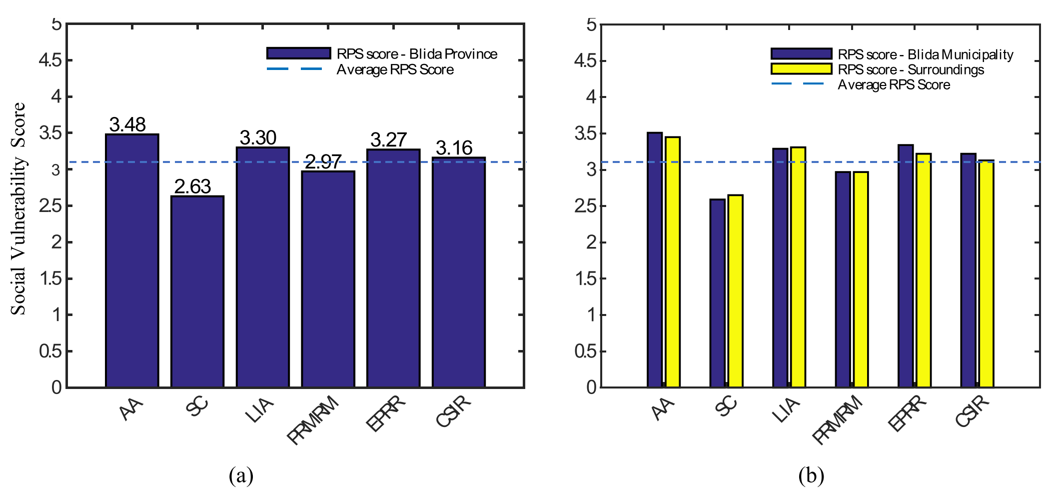

Fig. 6. RPS approach scores for (a) the province of Blida before disaggregation and (b) the municipality of Blida and surroundings after disaggregation (AA: Awareness & Advocacy; SC: Social Capacity; LIA: Legal and Institutional Arrangements; PRMRM: Planning, Regulation and Mainstreaming Risk Mitigation; EPRR: Emergency Preparedness, Response and Recovery; CSIR: Critical Service & Infrastructure Resilience).

of the hybrid approach and the resulting vulnerability scores are summarised in Table 10.

4.2. Disaggregated social vulnerability, Z-scored on income, density and education

The vulnerability score computed for the entire province of Blida was later disaggregated into the 25 identified municipalities previously shown in Fig. 2, in order to remain consistent with the evaluation carried out using the RPS approach. The specific features of the individual municipalities, (e.g. spatial characteristics of the city and their evolution with time) make the social vulnerability scores different from each other. Therefore, Z-score standardisation has been applied to the average score of distinct neighbourhoods to further understand the variation with respect to the average of the whole municipality. To this end, a proxy variable, X, is employed for which distinct values could be linked to each area. The standardization is obtained as follows:

$$Z = \frac{X - \mu}{\sigma} \quad (3)$$

$$\sigma = \sqrt{\frac{\sum (X - \mu)^2}{n - 1}} \quad (4)$$

Urban density, income and education, approximated from the outcome of the RPS approach, were post-processed and used to calculate the final results on two defined geographical levels, i.e. one, higher resolution, corresponding to a score to each single municipality, and the other, lower resolution, corresponding to the distinction between central Blida and the surrounding municipalities (Fig. 5), due to insufficiency of data. Using the feedback to the questionnaires, a vulnerability score has been accredited to the income, density and education variables for the municipality of Blida and for the surrounding municipalities. The deviation (Z) of each municipality's score (X) from the global average (μ) and respective standard deviation (σ), was computed for both resolution levels, where n is the number of enumerated variables. For example, the municipality of Blida has a population density of 2515.85 inhabitant per m2, while the surrounding cities have a density of 744.24 inhabitants/m2, on average. Subsequently, by employing the minimum (400 inhabitants/m2) and maximum (43079 inhabitants/m2) registered densities for the two identified zones, within a MIN-MAX normalisation, the obtained vulnerability value is 0.05 (or 0.25 on a scale of 0–5) for the commune of Blida and 0.01 (or 0.04 on a scale of 0–5) for the surrounding communes. Moreover, the average of the two vulnerability scores is computed (0.14 on a scale of 0–5). The term, X-μ, is now simply the vulnerability score of each zone minus the calculated average. The Z-score is thus obtained by computing the standard deviation (in Equation (4)) equal to 0.146 for the case of the population density. The density indicator was the only that could be used for the single-municipality resolution level (i.e. higher geographical resolution) given that the population data on such level was available. The vulnerability scores at the municipality level, which were z-scored on density, are shown in Fig. 7 (a), while the vulnerability scores for the lower resolution level, z-scored on all of the three aforementioned variables, are illustrated in Fig. 8 (a), along with the attributed average social vulnerability in Fig. 8 (b). For the sake of comparison, Fig. 7 (a) also presents the final social vulnerability assessment values (in red) obtained at the lower geographical resolution (i.e. the municipality of Blida and the aggregation of all surrounding cities) by averaging the social vulnerability scores z-scored on income, education and density illustrated in Fig. 8 (a).

The results of Fig. 7 show that the municipality of Ouled Yaich scores the highest in terms of vulnerability associated to density, which is likely due to the fact that the municipality has a population density of 9000 inhabitants per km^2, three times as much as the second municipality of Beni Merad (3300 inhabitants per km^2). The city of Blida, however, ranks third with almost 2500 inhabitants per km^2. This information remains relevant even when aggregating the adjacent municipalities to Blida in one single geographical unit.

While Fig. 7 presents the vulnerability score based on density of any given municipality, Fig. 8 (a) tends to illustrate the effect of all three indicators (i.e. income, education and density) on the overall social vulnerability of the province, when performing geographical data aggregation, due to the absence of extensive statistical data. Values reported in Fig. 8 (b) correspond to the average z-scored social vulnerability scores obtained in Fig. 8 (a). In such a way, the effect of income, education and density is presented in Fig. 8 (a) whose data is gathered from the RPS answers. Income and education scored lower for the main city of Blida and higher for the neighbouring municipalities. This can be interpreted as an effect of centralised institutions, facilities and businesses in Blida rather than the surrounding areas. Regarding density, when aggregating the municipalities, only two recorded higher social vulnerabilities than Blida (i.e. O. Yaich and Beni Merad) while all the others showed lower scores. As such, the aggregated geographical zone, on average, is associated to lower social vulnerability, when compared to the central municipality. The average obtained social

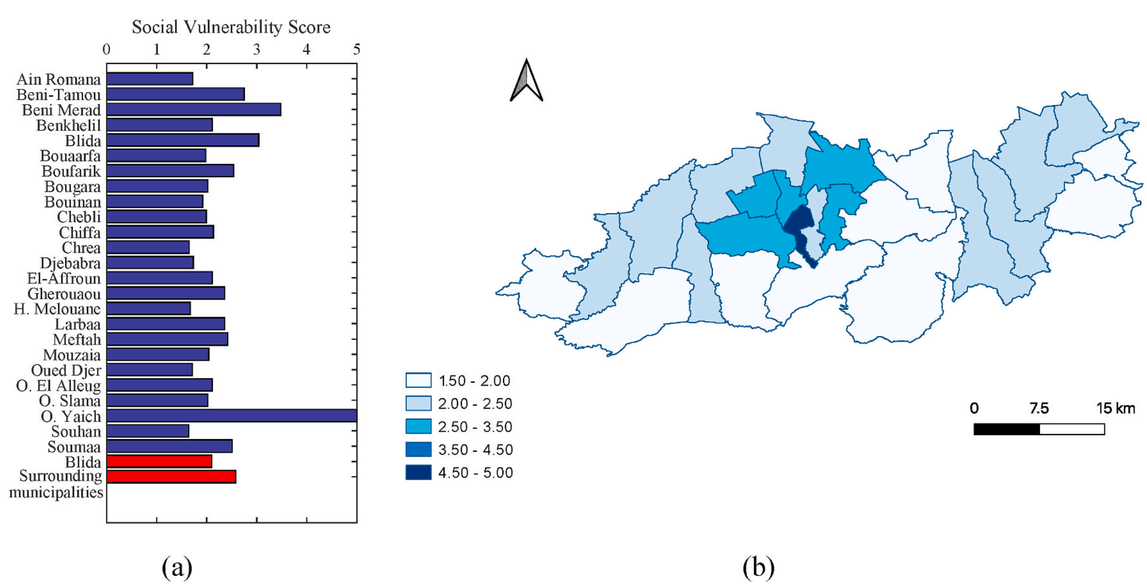

Fig. 7. (a) Social vulnerability z-scored on density for all the municipalities of the Blida province (b) geographical illustration of the social vulnerability scores.

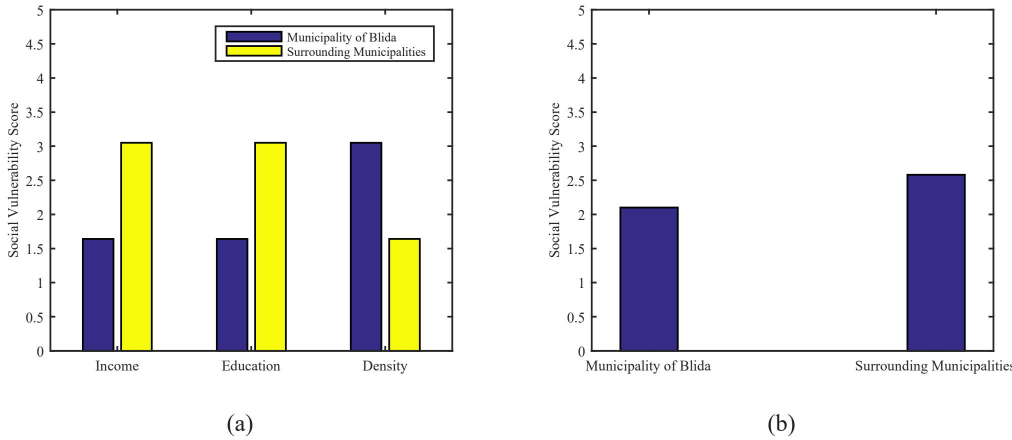

Fig. 8. (a) Social vulnerability, z-scored on income, education and density, of the province of Blida and (b) average vulnerability score for the two assessed geographic zones.

vulnerability scores for the two geographical resolution levels are 2.10 for Blida and 2.58 for the surrounding municipalities. The overall social vulnerability results show that while the resilience performance scorecard approach yielded uniform scores between the municipality of Blida and its surroundings with very low dispersion, the difference in social vulnerability levels can be attributed to the contrast in socio-economic conditions, mainly the levels of income, education and population density.

A similarity in results can be observed with other studies that have addressed the social vulnerability matter recently, such as the work done in Cerchiello et al. (2017, 2018) for the social vulnerability assessment of the city of Nablus in Palestine. The population expressed low awareness for themes especially related to planning, regulation and mainstreaming of risk mitigation, as well as critical service and infrastructure resilience. Additional studies such as [1,16,47] carried out an overall social vulnerability and population resilience assessment through incorporation of similar indicators (i.e. population, economy, infrastructure, etc.) on a district-based geographical setting for Portugal, Nepal and Ecuador respectively. The observed results of the aforementioned studies complement the study performed herein in validating the observations on the developed model. The registered scores for social vulnerability provide a relevantly fair match between these case study countries given the resemblances in census data provided, given a certain indicator.

5. Conclusions

This study presented a thorough evaluation of the seismic social vulnerability level in the province of Blida, Northern Algeria. Two distinct methodologies, (1) SoVI® and (2) Resilience Performance Scorecard RPS have been performed both separately and merged in a way to better describe and map the social vulnerability of the region. Consequently, the largest possible number of social dimensions relevant to the vulnerability nature of the problem were considered. The consideration of the RPS approach in this context was based on the simplified assumption that its resilience-related scores could be used, in an inversely proportional fashion, to characterise vulnerability and be compared with the SoVI® framework.

The first approach employed the census data for the Algerian provinces provided by the National Office of Statistics (ONS). The second one, benefitted from the contribution of the local population (scholars, general public, decision-makers), who participated in self-assessing supplementary dimensions relevant to the study by filling out ad-hoc questionnaires. The classical SoVI® approach comprised eight detailed indicators, which were subsequently extended on the basis of different variables, while the resilience performance scorecard approach was established with six dimensions of awareness. The main product of this study is an overall average score for social vulnerability, along with a model and mapping of the observed spatial distribution of vulnerability, obtained from both the adopted methodologies, as well as from their combination. Such a social vulnerability model and score can be convoluted with the hazard and physical vulnerability models to carry out integrated seismic risk calculations for the Algerian territory. The results of the application of the social vulnerability index yielded a score of 2.19, hence in the lower half of the vulnerability scale, reflecting the slightly better-than-average socio-economic reality of the case study province. On the other hand, the outcome of the resilience performance scorecard approach, denoted by a score for the "Awareness" indicator of 3.14, demonstrated that the population showed a medium-low sense of understanding to themes whose availability or lack can be respectively beneficial or detrimental to a society upon a natural hazard. When interpreting the results of the hybrid approach presented herein, it can be seen that the SoVI approach results tend to underestimate the RPS ones. Therefore, the proposed approach is useful to quantify other dimensions that cannot be readily measured through census data but rather through the engagement of the exposed community itself.

Overall, the two methodologies produced similar results, in terms of vulnerability score, 2.19 and 2.35, respectively, for the SoVI® without the added indicator "Awareness" and RPS-integrated approaches. When performed separately, the RPS methodology yielded a score of 3.16. This indicates how the awareness component did not, on average, particularly affect the overall vulnerability score obtained when using the SoVI® approach but nevertheless contributed to an increase in the vulnerability of the studied community. However, this can also be due to the low weight given to the RPS indicator "Awareness" that was integrated in the SoVI® approach. Should the weight of the quantitative side of RPS be higher, the differences between the originally proposed and the merged approaches would be higher and on the higher vulnerability side, which denotes the importance of the participatory nature of the RPS approach. When isolating the individual contribution of every socio-economic indicator, particular care should be allocated to education as it registered the highest vulnerability score of 3.57. Such information is particularly useful to governmental agencies whose aim should be to enforce the delivery of proper education to its population, which, in turn, can be favourable in increasing awareness and, subsequently, resilience. Moreover, to further characterise the social vulnerability of the case study community, factors such as income, education and density were obtained from the participatory scheme. These factors were then used, through the "z-score" approach, to gauge their effect on the overall vulnerability. Statistical analyses have shown that the differences in these socio-economic indicators between the two defined geographic zones can prove either beneficial or detrimental to the societal fabric. For example, a relatively higher level of income and education observed in the municipality of Blida has shown to be related to a lower social vulnerability level, when compared with the surrounding municipalities despite having a higher population density. Decision-makers can use this outcome to further reflect on the current situation and propose solutions to target specific sectors that require improvement.

Similar studies, previously highlighted in early sections, on social vulnerability and population resilience to hazards have been performed using the originally proposed social vulnerability index, the RPS approach, or both, depending on the scarcity of records and thus utilising proxies for data collection. The methodology to adopt to carry out such studies or analysis remains largely depending on the set of available data, case-study region or identified objective, which can pose limitations on the adopted social vulnerability score (i.e. defining a score of 0–5 in which the resilience of a certain population is quantified). Furthermore, the resolution level of these studies depends vastly on the identification and availability of socio-economic databases, which require the identification and inclusion of relevant variables for measuring social vulnerability thus dictating the scale at which such studies should be performed (i.e. global or national level, sub-national level, municipal level, etc.). Stakeholders and decision-makers are encouraged to develop these indices and aid local institutes with data mining and collection. In such a way, these indices would be more based on share-holders contribution and local knowledge of the socio-economic context in the area of interest, leading to the development of higher-resolution indices.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijdrr.2020.101821.

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