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TERRITORIAL VULNERABILITY ASSESSMENT, AS A DECISION-MAKING TOOL FOR RISK MANAGEMENT, CASE OF ALGIERS, ALGERIA

Nadir Louchahi[1-2*], Ali Hadjiedj[1-2] and Aziz Hami[3]

[1]*Faculty of Earth Sciences, Geography and Territorial Planning (FSTGAT), University of Sciences and Technologies Houari Boumedienne (USTHB) Algiers, Algeria*

[2] *Laboratory of Research and Studies in Urban Planning LREAU/ USTHB, Algiers, Algeria*

[3] *Algerian Company of Works of Studies, Engineering and Management EURL SATEIG, Algiers, Algeria.*

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Abstract: Our work aims at assessing the urban vulnerability of territories exposed to multiple major natural hazards by using an integrated cartographic method that is based on a multicriteria analysis. We aim at analyzing the system of territorial vulnerability to major natural hazards, namely: earthquakes, floods and landslides in the eastern part of Algiers bay. Our methodological approach is based on developing a Geographical Information System (GIS), which will integrate the different databases. This will allow us to improve the models of the spatial analysis of vulnerability and to develop a planning tool for decision making in risk management. This article advocates a multidisciplinary framework for territorial vulnerability assessment that links socio-economic conditions (social vulnerability) to physical and environmental conditions (natural hazards) and reduction conditions of urban system (response capacity) that can be adapted to any geographical location in the context of disaster risk reduction. In this regard, our article examines the possibility of integrating social vulnerability, exposure to hazards and response capacity into the analysis of natural risks in Algiers. More specifically, vulnerability indicators were used to assess and map the territorial vulnerability index at the municipal level.

Keywords: Vulnerability; Naturel Hazard; Risk; Decision Making, indicators, Gis

* Correspondence to: Louchahi Nadir Tel : +213 560 14 65 80. *E-mail:* nlouchahi@usthb.dz

INTRODUCTION

In recent decades, the impact of natural hazards has increased due to high urbanization in high-risk areas, marked by the lack of relevant spatial planning and the increase in the frequency and intensity of extreme events resulting from climate change (Frigerio *et al*., 2016, Pachauri *et al*., 2014). Disasters and disasters occur when potentially damaging natural phenomena interact with risk factors that are physical, social, economic and environmental (Birkmann, 2006).

The main focus of the research is disaster management was based on risk assessment, however, over the past two decades, vulnerability assessment has also emerged as an important area of research.

The most important aspect of disaster risk reduction is to establish a better understanding of disaster risk reduction factors and their interactions: hazards that pose a significant threat and societal vulnerabilities (Birkmann, 2006).

From this point, the vulnerability of a territory can be modeled by studying the potential hazard of the place on the basis of the interaction between risk (measuring potential damage, health status, livelihoods, goods and services, which could occur to a society over specified future periods) and reduction (measures to reduce risks or reduce their impact) (Cutter and Emrich, 2006).

Natural hazards can be more or less devastating in relation to vulnerability, which depends on the time (time) and place (space) at which damaging events occur and the social and economic conditions of the affected population. This implies the need to integrate research on territorial vulnerability as a decision-making tool in urban planning.

Algiers is the political and economic capital city of Algeria, a Mediterranean metropolis covering an area of 808, 89 km2 (Algiers, 2015) with almost 3,154,792 inhabitants. In recent years the local authorities of the wilaya of Algiers (wilaya in Arabic means district or department) launched a new urban development strategy (Parquexpo, 2016), including a rich program of projects and basic infrastructures in order to promote the city at the global scale and ensure a better functioning.

The territory of the wilaya of Algiers is exposed to many hazards of natural origin such as earthquakes, liquefaction, floods and landslides (Machane *et al*., 2008, Guemache *et al*., 2010).

The greatest risk Algiers has to cope with is related to the earthquakes (Bounif *et al*., 2004, Harbi *et al*., 2007b, Harbi *et al*., 2007a, Harbi *et al*., 2015). In this context marked by the multitude and the severity of the hazards (the city sustained damage during the Zemmouri-Boumerdes 2003 earthquake (M 6.8, I0 X EMS) with maximum intensity ranging from VI to X in the Algiers wilaya (Harbi *et al*., 2007b), and experienced a flood at Bab El Oued in 2001 (Moore *et al*., 2005)) and the number and the importance of the demographic, socio-economic, political and environmental stakes which conceals the city of Algiers (Parquexpo, 2016), the issue of natural risk management became essential for local authorities, particularly with the experiences that showed the fragility of the Algiers urban system and the limits and inefficiency of risk management policies led by the decision-makers. In fact, the programs of management and prevention of natural risks did not meet the expectations of the decision-makers and did not allow them to have a good visibility and a wide scope of intervention at all levels and scales, to efficiently conduct policies and programs of urban planning and territorial development. This is what motivated the present work. We noticed the absence of the appropriate operational tools and the existence of several document regarding each natural hazard at different scales and spatial coverage that are generally misinterpreted and misunderstood and that limit the complex field of risk prevention and management.

Given the challenges identified, the main objective of this work is to present and develop an approach that will allow the territorial vulnerability to multiple hazards of a GIS-based system to be assessed in a coherent manner. The method proposed here is based on the selection and characterization of elements that can be used as vulnerability indicators. In this study, we consider territorial vulnerability varies according to social vulnerability, exposure to natural hazards and response capacity.

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The main idea of our article is based on an integrated cartographic approach by means of a GIS database. This database will allow us to estimate the urban vulnerability in a multidimensional structure that produces interaction between the major natural hazards, the social vulnerability and the responsiveness. To achieve our objective and produce a synthetic map of the territorial vulnerability, we use a multicriteria analysis based on a set of indicators that reflect the degree of vulnerability of the exposed systems.

Review of the scientific literature

Vulnerability is a key concept in understanding the state of a system or its disposition in the face of harmful phenomena. In addition, the vulnerability of the system is its ability to withstand exogenous threats.

Vulnerability is a function of exposure to a stressor, effect (also called potential sensitivity) and recovery potential (also called resilience or adaptive capacity) ((De Lange *et al*., 2010, Turner *et al*., 2003).

Vulnerability is a complex concept, as there is no consensus on its precise meaning (Khan, 2012). The multidisciplinary nature of contributions to vulnerability theory is evolving towards many competing definitions (Cutter and Emrich, 2006, Menoni *et al*., 2012) Nevertheless, most of these definitions deal with vulnerability according to the susceptibility of the loss and the ability to recover, called "Resilience".

The natural sciences are considered as the basis for the conventional allocation of disasters; knowing that disasters and calamities are part of nature and the environment. In the engineering-based paradigm, most disaster research focuses on disaster risk exposure and biophysical vulnerability assessment (Cutter and Finch, 2008, Turner *et al*., 2003).

However, in recent decades, several studies have refused to take this perspective, and have instead considered disasters to be social constructions (Adger *et al*., 2011, Cutter *et al*., 2000, Tierney, 2007).

In addition, it can be said that physical vulnerability is similar to that addressed in the traditional impact method, based on the natural sciences. Physical vulnerability underlines the probability of exposure to hazards associated with natural disasters (Cutter, 2003).

In contrast, social vulnerability refers to the state prior to disasters (Finch *et al*., 2010, Schmidtlein *et al*., 2011), and includes the social, economic, political and institutional aspects elements.

The 1990, which the United Nations (the United Nations) devoted to natural disaster reduction, led to the redefinition of assessment concepts, methods and tools (Veyret *et al*., 2003, Dauphiné, 2002).

Also, the shift from the "Hazard paradigm", which considers risk as an otherness, to the consideration of risk as a social construct, with an emphasis on vulnerability, has been confirmed (Pigeon, 2002).

Our study is based on a spatial analysis of the urban system at the local (communal) level, which takes into consideration the problems associated with natural hazards. In this article, we propose a general framework for the development of indicators of territorial vulnerability and attempt to elucidate the spatial distribution of vulnerability in these different dimensions, while explaining the complex and dynamic nature of the concept studied, given that vulnerability is multi-faceted, evolving and dynamic, varying over time and on several spatial scales.

In addition, vulnerability has been founded as a key concept, taking into account the different dimensions: physical, social and functional (Gleyze and Reghezza, 2007, Wisner, 2003). However, while the concepts have evolved under the impetus of international institutions, and the tools have been enriched by the development of computer tools (White *et al*., 2001), the methods used remain based on generalized additive models (Barnett *et al*., 2008, Kasperson, 2005), which do not make it possible to account for the complex relationships between the different dimensions of vulnerability, which require analysis of their interactions (Dauphiné and Provitolo, 2003).

These formal vulnerability estimation methods integrate the hazards of a territory, the fragility of exposed systems, as well as adaptive capacities; unfortunately, the latter are confronted with methodological obstacles with a view to two main problems: the number of factors taken into account and their heterogeneity, which must be reduced in order to facilitate statistical processing and cartographic production.

This reflection is the starting point of our work, which aims to overcome these methodological constraints, the objective of which is to establish a numerical analysis method for vulnerability assessment, using a synthetic approach that uses geographical information systems.

MATERIALS AND METHOD

The study area

Our study area is located in the eastern part of the bay of Algiers and includes two municipalities namely Bordj El Bahri and El Marsa. It spreads over 11.36 km² (**Fig. 1**) gathering 68559 inhabitants (ONS, 2011).

This zone is characterized by a fragile physical environment due to the presence of active seismic faults, unstable ground (rockfalls), and flood zones around Oued El Hamiz. Its urban area is characterized by a high population density on an average of 7457 inhabitants/km² (Algiers, 2015) as well as by a large number of urban issues (housing, activities, equipment, basic infrastructures). In addition to the hazards, the study area has to cope with, a strategic plan for the development of Algiers city is nowadays launched and includes large scale structuring system. All these conditions make our study area the ideal place to perform research work on governance of natural risks in urban areas, particularly the numerical assessment of the territorial vulnerability to natural risks.

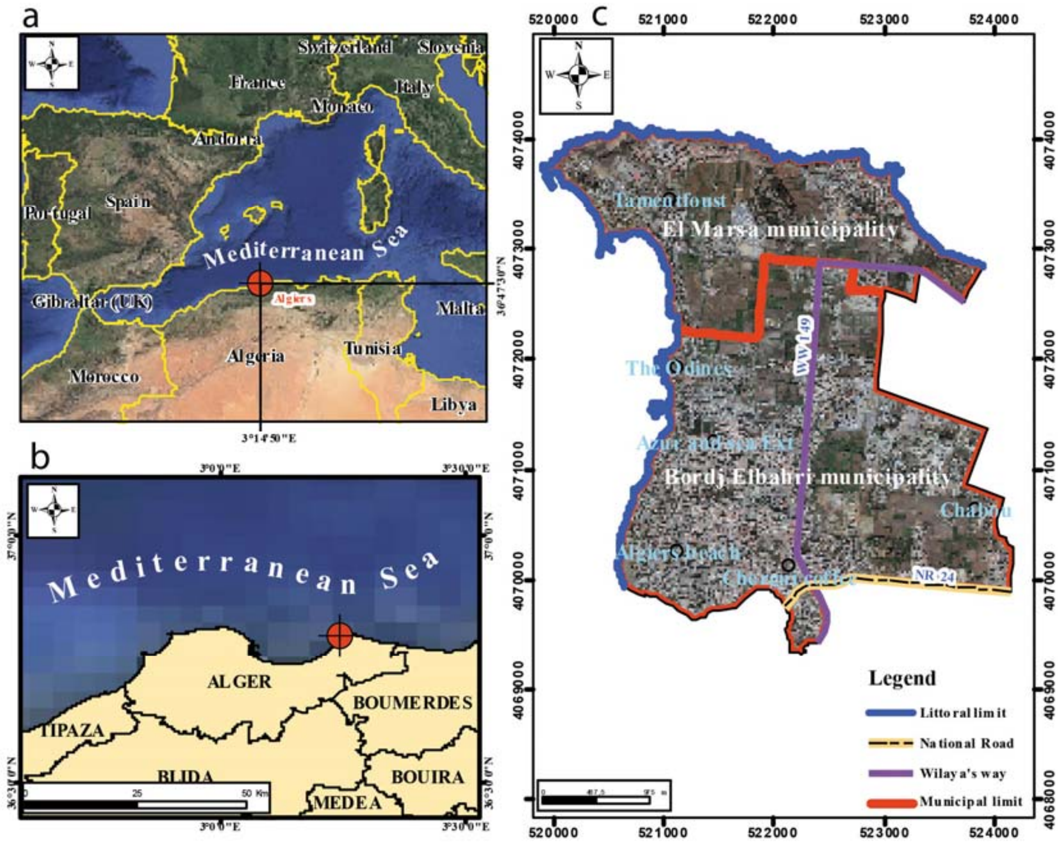


Fig. 1 Presentation of the study area (a. Location of the study area within the world, b. Location of the study area within the Algiers Wilaya, c. Administrative division of the study area).

Methodology

Our study aims at measuring the territorial vulnerability according to the hierarchical multicriteria method, within the framework of an approach that is based on the principles of the preventive urban planning that is organized in a multidimensional hierarchical structure (factors, criteria and indices) linking three main sub-objectives that are: major natural hazards, social vulnerability and responsiveness of the exposed system. This will lead to the analysis and assessment of the vulnerability of areas, from which the vulnerability is created and disseminated within a territory, causing effects that may disturb, compromise or even interrupt the functioning and the development of this territory (D'Ercole and Metzger, 2009). To that purpose an attempt is made to develop a hierarchical, multi-criteria method for assessing the territorial vulnerability to major natural hazards, set up in a Geographic Information System (GIS) at a minor spatial analysis scale, namely 80 districts of two municipalities that are Bordj El Bahri and El Marsa, according to the general census of population and housing (ONS, 2011). We extracted our database from this census that produced the most reliable and complete data with a random error ranging from 0.7 and 2.5% between the stocks per district and the totals for the whole municipality. We selected a database including the main characteristics of the vulnerability related to the socio-demographic issues (population density, age group of vulnerable people, unemployment rate, etc.). To this database we added other data that we collected from the managing administrations (ministries, prefectures, companies, etc.) and fieldwork on the infrastructures, activities, built environment, and networks. This will allow us to take into account the social, physical vulnerability and the responsiveness. The extension of the expected effects of the hazards were also considered as follows: 1) for the seismic hazard we used the data inferred from the microzonation study of JICA; 2) for the flooding we considered the data of the master plan of the urban development; 3) for the landslides and rockfalls we used the study of the vulnerability of Algiers city. As all these data are approximate, especially those related to the seismic intensity (a qualitative measure), we decided to perform a relative processing for each district. This approach seemed to us the most reasonable one. In light of this, the GIS and the sequence of the statistical methods allow to integrate these databases, to analyze the spatial interactions between hazards, social vulnerability and responsiveness, and to provide homogeneous areas (Cutter and Emrich, 2006).

The method presented in this work consists of both a qualitative and quantitative operational approach as well as a spatial analysis using a geographic information system (GIS) and statistical modelling.

The effective use of both methods (quantitative and qualitative) and the different tools (geo-spatial tools, statistical and other techniques) can lead to the improvement of risk research in an operational way and develop methods for analyzing and assessing territorial vulnerability (Yeager and Steiger, 2013).

The methodological framework for assessing territorial vulnerability to major natural hazards can be summarized in three main steps: (a) construct indicators of territorial vulnerability, (b) Perform a multivariate statistical analysis on the selection and aggregation of indicators, and (c) spatialization and vulnerability mapping.

Stages of the development of the estimation of the territorial vulnerability by the Hierarchical multi-criteria method based on GIS

The analysis that is done at the scale of the district for the two municipalities of the wilaya of Algiers is 80 spatial units. The first step consists in identifying the core indicators characterizing the vulnerability of the exposed urban system urban according to a tree structure. This structure is constituted by the main objective that is the territorial vulnerability and three sub-objectives, which are the degree of exposure to major natural hazards, the social vulnerability and the responsiveness (or capacity response) of the urban system. These three sub-objectives are themselves subdivided into criteria of vulnerability.

Definition of the Core Indicators of Vulnerability: Typology and Analysis

Many indicators influence the vulnerability of societies. However, the main indicators are: financial resources, education, gender, age, human development, physical and mental capacity, exposure to hazards, response capacity and social capital (Jabareen, 2013, Ojerio *et al*., 2010).

Vulnerability is a concept applied in several areas of research, and there is no consensus on vulnerability indicators. Researchers in the field of natural disasters accept the idea with regard to certain primary factors that affect territorial vulnerability and these components, unlike some factors will serve as a means of measuring these indicators.

Based on a literature review, this study compiles the factors and indicators identified and applied in territorial vulnerability studies. According to most studies on social and territorial vulnerability (Adger *et al*., 2005, Cutter, 2003, Morrow, 1999). The most important indicators of territorial vulnerability are based on disaster response capacity.

The study framework proposed here involves four main dimensions: social characteristics, economic characteristics, physical characteristics, response capacity. Most research considers these dimensions because they are crucial dimensions that truly influence the capacity of a disaster response society.

Territorial vulnerability assessment frame

The assessment framework for the territorial vulnerability analysis includes these three structuring elements: (a) the study of social vulnerability, exposure to natural hazards and response capacity by developing indicators, (b) the search for statistical processing measures for the quantification and aggregation of indicators, and (c) mapping (GIS) of the composite index of territorial vulnerability.

This work aims to develop a model that will give priority to intervention mechanisms in a territory following a natural disaster, based on the estimation of the impact of the various factors in this area and the evolution of the territorial system. The indicators are based on a systemic approach to vulnerability. The analysis structure makes it possible to approach the territorial system as much as a complex element composed of several subsystems (social, economic, environmental, etc.) in order to analyze the interrelationships between the elements of this system and to measure the vulnerability of the territory.

In this work, the vulnerability is a function of three important terms and is expressed according to the following equation:

$$TVI = f(E, S, R) \quad (1)$$

TVI: Territorial vulnerability index
H: Natural Hazard
S: Social vulnerability,
R: Response capacity (responsiveness)

Indicators to major natural hazards

The determination of the indicators of the major natural hazard is based on the analysis of the hazards experienced by our study area from the point of view of intensity, probability of occurrence, and damage impact. The Algiers department is located in a seismogenic zone that experienced several damaging to destructive earthquakes (Harbi *et al*., 2017). It comprises and it is surrounded by active to potentially active faults **"Fig. 2"** (JICA, 2006, Meghraoui, 1988, Maouche *et* *al*., 2011). In our work we took into account the earthquake intensity damage according to EMS 98 as one of the most pertinent parameter to spatialize, analyze and assess the damage that could occur in the future in terms of seismic scenario for a return period of 475 years and the maximum magnitude of earthquakes generated by the known active and potentially active faults (JICA, 2006, EAU/IAU-IDF/BRGM, 2012).

Regarding the secondary geological hazard that is related to earthquakes, namely the liquefaction, we used the indicator of susceptibility to liquefaction resulting from the seismic micro-zoning study of the wilaya of Algiers (CGS, 2018). This synthesis map is the result of the superposition of three main parameters which are: the nature of soil (sandy formation and its granulometry such as low-lift sand), the shallow water table and the strong seismicity of the region. Our study area is generally characterized by a moderate susceptibility to liquefaction with the presence of some small areas that are highly liquefiable.

Marine erosion is also a natural hazard, even less important, that affects our study area at the foot of the cliff in the municipality of El Marsa. These marine erosions induce rockfalls and rockslides and are considered in this study as indicator of a ground motion. Our area is classified as at moderate risk to landslides (BURGEAP, 2005).The intense rainfall, the topography, and the low permeability of the soil make the Mitidja basin vulnerable to flooding. To address the flooding hazard, we selected as a parameter, the marine transgression and the flood-prone areas of Oued El Hamiz (El Hamiz river), which is characterized by a return period of 100 years. The risk related to flooding in our study zone is considered as moderate (Parquexpo, 2016, EAU/IAU-IDF/BRGM, 2012). For these two criteria the degree of risk is moderate.

Indicators of social vulnerability

After a review of the literature review on the subject and with the aim of selecting the most relevant factors characterizing social vulnerability (Cutter, 2003, Birkmann, 2006, Utami, 2008, Cutter and Finch, 2008, Wood *et al*., 2010) five (05) indicators were selected: age, gender, employment, education and anthropization. Based on these indicators, 09 indirect variables were taken into account for each district of each commune, which explain the socio-economic situation of the Algerian population. The conditions that affect a community's ability to prepare for, respond to, and recover from hazards and disasters. Variables explain both positive and negative factors that increase or reduce social vulnerability.

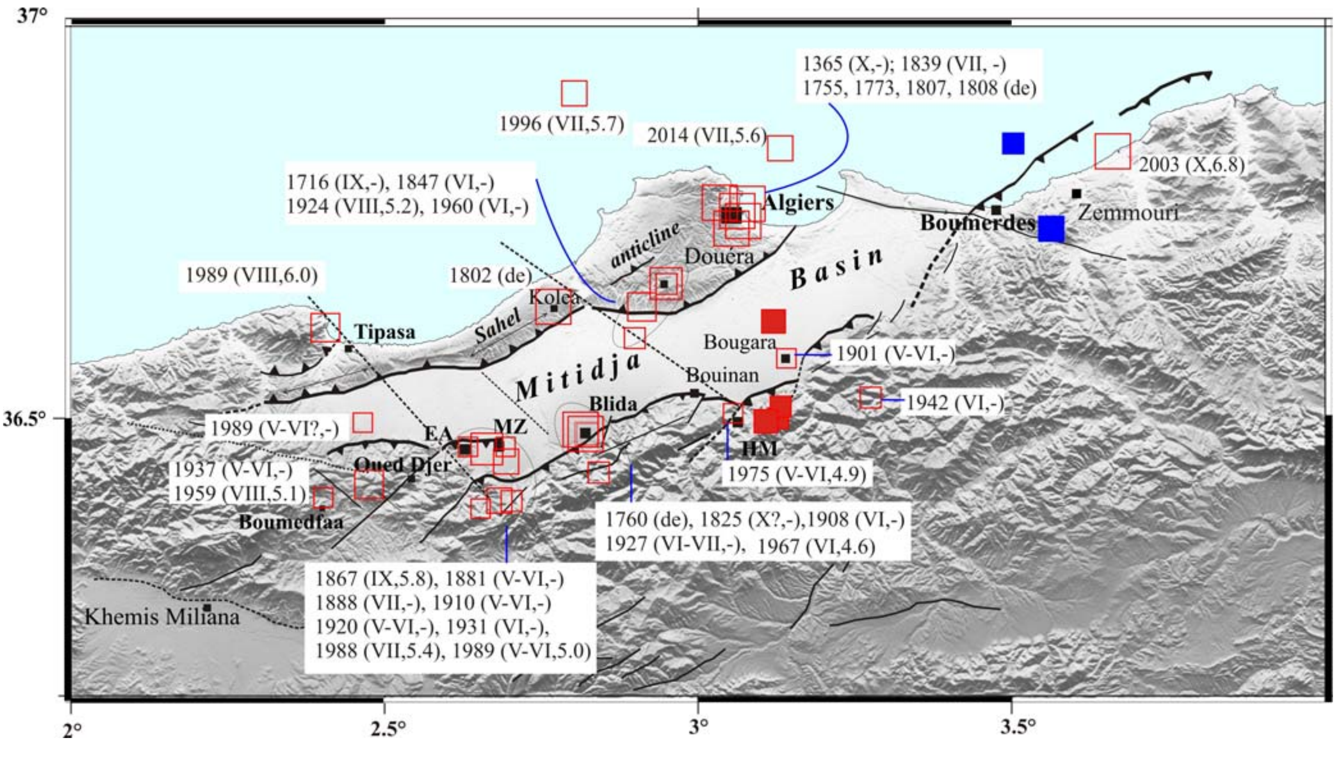


Fig. 2 The most significant earthquakes that occurred in the Mitidja basin, including our study area, from 1760 - to now; the blue squares correspond to the largest aftershocks of the 2003 Zemmouri earthquake whereas the red solid squares correspond to the largest seismic events of the 2013 and 2014 Hammam Melouane seismic sequence; each event in the different transparent boxes is referred to by the year of its occurrence, the epicentral intensity I_0 and its magnitude when available (year (I_0,M)); (de): destructive event. The different active or potentially active faults considered in our study are also shown (as in Harbi *et al*. 2017).

A brief explanation of each indicator is given below: The age indicator is a relevant dimension for assessing social vulnerability. There is a general consensus that children are more vulnerable because they are highly dependent on adults. Ageing can also influence vulnerability because this population group has limited capacity to respond to disasters. Among the most commonly used variables are the percentage of children under 14 years of age and people over 60 years of age (Bolin and Stanford, 1991, Morrow, 1999, Burton and Cutter, 2008, Frazier *et al*., 2014).

Gender in risk studies represented by the female population rate is generally used since family responsibilities and particular cultural norms make women weaker than men in responding to and recovering from disasters (Cutter, 2003).

Employment is often linked to the potential loss of work activities following a dangerous event, the variable representing this indicator is the unemployment rate (Cutter, 2003). Education or education level reveals the ability to understand information on emergency plans or warning information and to avoid dangerous situations (Elstad, 1996, Morrow, 1999).

The anthropization indicator indicates the degree of urbanization and population density, it is often unlikely that rapid urban growth of territories will lead to inefficient services to the population, and several problems related to the functioning of the urban system (building density: concentration of activities, services, wealth, especially in the absence of effective urban planning) (Cutter, 2003).

The construction quality variable represents the susceptibility of buildings to damage following the onset of a damaging phenomenon (natural hazard) (Bolin and Stanford, 1991, Cutter, 2003). It should be noted that all indicators relating to social vulnerability have been extracted from the(ONS, 2011, Parquexpo, 2016).

Response capacity (responsiveness)

Regarding the response capacity, we considered as main indicator the accessibility to the various emergency services at the time of the crisis, particularly health services, civil protection (Armaş, 2012, Carreño *et al*., 2007, Barczak and Grivault, 2007), security services (Armaş, 2012, Carreño *et al*., 2007) and shelters (Armaş, 2012, Carreño *et al*., 2007). This will ensure the evacuation of the population and a more efficient management of the post-crisis.

In terms of response capacity and after consulting the literature review, all the indicators selected are part of the measurement of the response capacity of the urban system exposed to multiple natural hazards in order to reduce human losses and damage. The principle of measuring response capacity is based on the accessibility of crisis services that intervene at the time of the hazard event to support the affected population and the organisation of relief operations. Four (04) indicators were selected to assess response capacity (health services, firefighters, shelter sites and security services).

Within these indicators, 06 variables were taken into consideration: The first indicator relating to health services, which are considered as strategic equipment during disasters, is the provision of health care for the injured and disaster victims. The second indicator is that of the fire brigade services that provide evacuation of disaster victims to secure areas, health facilities and places of refuge. The third indicator concerns places of refuge, which are the most secure places at the time of the crisis, and are used to receive populations in dangerous situations. The fourth indicator, relating to safety services, which have an important role in organizing road traffic during the crisis and establishing safety and security in the affected areas in order to avoid panic and ensure the smooth running of relief operations (Armaş, 2012, Barczak and Grivault, 2007, Carreño *et al*., 2007). The multidimensional structure for evaluating the territorial vulnerability to major natural hazards is represented in **Fig. 3**.

The Construction of the georeferenced database using GIS

Once we identified the indicators, we proceeded with the construction of a georeferenced database using GIS and from which the conditioning factors of the territorial vulnerability may be retrieved. The reliability of our results mainly depends on the quality and the quantity of the available data, the scale of the considered grid, the analysis method used, and the appropriate modeling.

First, we collected the data of our study zone from different institutions, documents, previous studies, and field surveys. To easily integrate the data and the calculation of the different factors, we re-sampled the thematic layers generated under GIS into the reference spatial grid that is the district. The district comes from the urban redistricting conducted during the 2008 general census of population and housing (RGPH, Avril 2008). All maps were geo-referenced in the local projection system of Algeria (UTM zone 31 WGS 84 - Geodetic reference system) and statistical analyses of the data were performed **Table 1**.

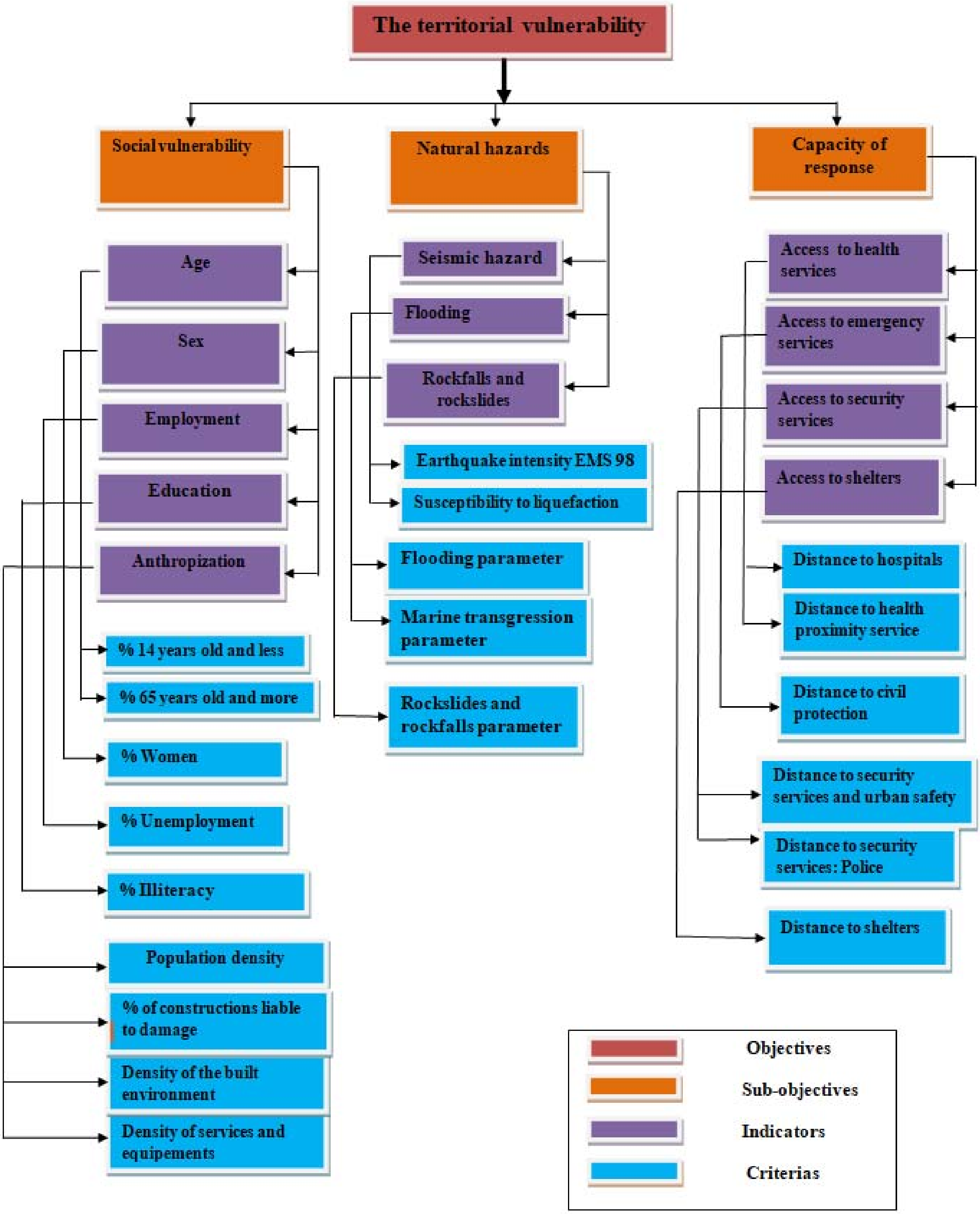


Fig. 3 The multidimensional structure for assessinging the territorial vulnerability to major natural hazards.

Table. 1 Spatial database of the study area

	Data layer	Source of the database
Factors of natural hazards exposure	Earthquake intensities (EMS 98)	Earthquake intensities map, Algiers JICA 2006 seismic microzonation study (Japan International Cooperation Agency) and studies (BRGM 2012)
	Liquefaction	1: 10,000 Liquefaction Susceptibility Map, Seismic Microzoning Study of the Algiers wilaya from C.G.S (National Center for Applied Research in Earthquake Engineering).
	Flood	Alsat 2A satellite images at 1: 10,000 scale (resolution 2.5 m), 1: 25,000 scale topographic map, field survey. Database from the 04 meteorological stations of the ANRH (National Agency of Meteorology and Hydrology) and the NOM (National Office of Meteorology)
	Rockfalls and rockslides	Landslide Inventory Database, 1: 10,000 Geological Maps, satellite images (Alsat 2A) at 1: 10,000 scale, 1: 10,000 scale aerial photos, Google Earth data, field surveys.
Factor of the social vulnerability	Age, sex, education and employment	General Census of Habitat and Population (RGPH 2008) from National Office of Statistics ONS
	Anthropization	General Census of Habitat and Population (RGPH 2008), National Office of Statistics ONS and field survey, Land Cover Map at a scale of 1: 10,000 (Master Plan of Planning and Urban Development PDAU) from the direction of urban planning of the wilaya of Algiers
Factors of response capacity	Distance to health facilities	Google Earth data, aerial photos, field survey.
	Distance to Firefighters Emergency Services	Google Earth data, field survey
	Distance to security services	Google Earth data, field survey
	Distance to shelters	Google Earth data, field survey

The normalization of the basic indicators by the Min / Max normalization method

In view of the heterogeneity of the units of measurement for each indicator and in order to enable the comparison of the various available data, we standardized the data at a normative scale ranging from 0 to 100 with respect to the importance of each indicator to the vulnerability. The assessment of the alternatives may be expressed in terms of different scales (ordinal, interval, ratio). The most appropriate normalization method in our case is the Min / Max normalization “Table 2”. This method saves the distribution of the original scores at an approximate scale factor and transforms all the scores into the interval [0, 100]. The standardized Min-Max score for the test score is given by the following equation:

$$\textit{Normalized value} = \frac{(\textit{original} - \textit{MIN}) \times (\mathbf{max} - \mathbf{min})}{(\textit{MAX} - \textit{MIN}) + \mathbf{min}} \quad (2)$$

where Normalized value is Normalized value in target interval, MIN and MAX are original intervals, min and max are target intervals, and original is value in original interval.

Intra-factors and intra-criteria weighting by the Analytic Hierarchy Process (AHP) method

In our study we selected the methodology developed by (Saaty, 2008) that corresponds to the Analytic Hierarchy Process. The advantage of this method lies on its simplicity, clarity, flexibility, and adaptability (Svoray *et al*., 2005). Besides, it is the only method that allows us to check the coherency of the judgments of comparison. In order to get a satisfactory global view on the vulnerability model that we have to develop, we first describe the complex situation. This hierarchical decomposition is based on a typology that combines the three main components of the vulnerabilities, considered as sub-objectives in our tree structure (the exposure to natural hazards, social vulnerability, the response capacity) themselves precisely subdivided into vulnerability indicators (Merunka, 1987, Griot, 2007). The second step of the weighting consisted in using the specific scale developed by (Saaty, 2008). The advantage of this assessment grid is that it allows measuring the subjective and the formally quantitative judgments as well, and the degree of importance of one of the elements of the hierarchy with respect to the other **Table 3**.

Table 2. Results of intra-indicators normalization

Criteria	Minimum values	Normalization (0 to 100)	Maximum Values	Normalization (0 to 100)
Vulnerable age group 0-14 years	26,86 %	40	28,37 %	45
Vulnerable age group 60 years and over	6,57 %	12	7, 83 %	15
Female population rate	0	0	59,29 %	60
Illiteracy rate	11,90 %	55	12 ,40 %	52
Unemployment rate	0	20	68,77 %	80
Population density / km2	0	10	50084	90
Construction rate for professional use	0	0	16, 83 %	80
Occupied population rate	0	20	36,84%	65
Density of the urban environment	0	5	95,99	80
Rate of the susceptibility of constructions to damage	0	0	100 %	100
Number of equipment and urban works	0	0	6	75
Intensity in the sahel fault area	VII	50	VII-VIII	55
Intensity in the chenoua fault area	V	20	V-VI	30
Intensity in the Blida fault area	VII	50	VII-VIII	55
Intensity in the khireddine fault area	VI	40	VI	40
Intensity in the Thénia fault area	VII	60	VIII	60
Intensity in the zemmouri fault area	VI-VII	45	VII	50
Intensity in the ain benian fault area	V	20	V	20
Liquefaction factor	Null	0	Strong	80
Percentage of the flood zone (100% = 50 moderate hazard	0	0	97, 81 %	49
Percentage of the coastal zone (100% = 50 moderate hazard	0	0	100%	50
Rockslide, Rockfalls	0	0	40, 93 %	20
Accessibility to health services: hospital	3646,37 m	35	7704,88m	80
Accessibility to health services of proximity	337,65m	7	2760,73m	70
Accessibility to civil protection	142,16m	0	5443,69m	70
Accessibility to security services: Police station	247,66m	7	4083,36m	70
Accessibility to security services: urban safety	399,01m	15	2952,31m	60
Access to shelters	50,22m	5	2461,65m	80

Table 3.Binary scale of comparisons (Saaty 2008)

Intensity of importance	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment strongly favor one element over another
5	High importance	The evidence favoring one element over another is of the highest possible order of affirmation
7	Very high importance	An element is favor very strongly over another, its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between adjacent scale values	When compromise is needed
Reciprocals	Opposites	Used for inverse comparison

We performed the weighting of the priorities and then classified the different elements according to their relative importance by means of matrixes. Proceeding in that way allowed us to compare two by two the elements according to given criteria (Griot, 2003). From these matrixes, we inferred questionnaires that we used during semi-structured interviews with 35 experts in this field (PhD students, University teachers, researchers, engineers, and the elected officials of our study zone). The last step consisted in carrying out a specific processing to aggregate the appreciations and judgments of the experts. Then we calculated the Eigen vectors of the matrixes judgment to provide the vulnerability functions that determine the priorities.

The final weight for each conditioning factor is given with a consistency rate (CR) expressed by:

$$\boldsymbol{CR} = \frac{\boldsymbol{CI}}{\boldsymbol{RI}} \qquad (4)$$

where RI is the average of the consistency index obtained as a function of the order of the matrix given by Saaty and CI is the consistency index expressed by :

Table.4 Preferences and weights of conditioning factors by analytical hierarchy:

Indicateur	(1)	(2)	(3)	(4)	(5)	Weight (W)	Weight %
(1)Age	1	2	2	3	2	0,331	33,10
(2) Sex	½	1	3	4	3	0,234	23,40
(3) Anthropization	½	1/3	1	3	3	0,166	16,60
(4) Education	1/3	¼	1/3	1	2	0,124	12,40
(5) Employment	½	1/3	1/3	1/2	1	0,145	14,50

λmax = 05.05; CI = 0.0110 = 1.10; consistency ratio CR= 0.005

$$CI = \frac{\lambda_{\max} - n}{(n-1)} \quad (5)$$

where λmax is the largest value of the matrix and can be easily calculated from the matrix, and n is the order of the matrix.If CR is less than 10%, then the matrix can be considered to have an acceptable consistency (Saaty 1977).A CR greater than 10% requires a revision of the judgment in the matrix due to inconsistent treatment of a particular assessment factor. Finally, the territorial vulnerability map using the AHP model was constructed using the following equation:

$$TV_{AHP} = (Social\ Vulnerability \times W_{AHP}) + (Natural\ Hazard \times W_{AHP}) + (Response\ Capacity \times W_{AHP}) \quad (6)$$

$$SV_{AHP} = (Age \times W_{AHP}) + (Sex \times W_{AHP}) + (Anthropization \times W_{AHP}) + (Education \times W_{AHP}) + (Employment \times W_{AHP}) \quad (7)$$

$$NH_{AHP} = (Seismic\ Hazard \times W_{AHP}) + (Flooding \times W_{AHP}) + (Rockfalls\ and\ Rockslides \times W_{AHP}) \quad (8)$$

$$RC_{AHP} = (Access\ to\ health\ services \times W_{AHP}) + (Access\ to\ emergency\ services \times W_{AHP}) + (Access\ to\ security\ services \times W_{AHP}) + (Access\ to\ Shelters \times W_{AHP}) \quad (9)$$

$$TV_{AHP} = (0.30 \times Social\ Vulnerability) + (0.40 \times Natural\ Hazard) + (0.30 \times Response\ Capacity) \quad (10)$$

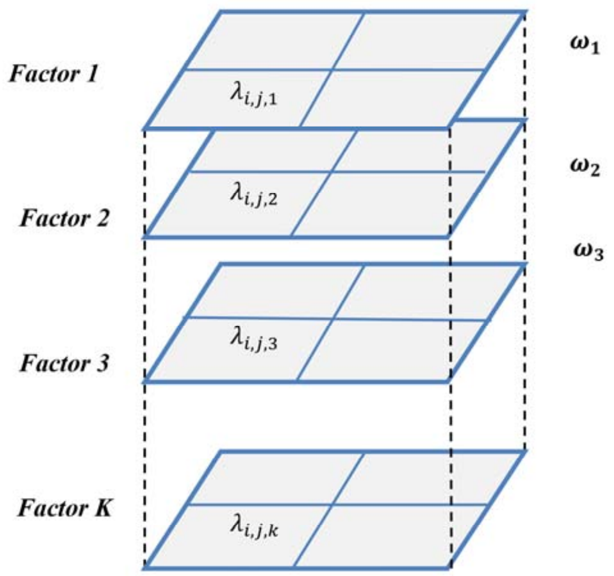
$$SV_{AHP} = (0.331 \times Age) + (0.234 \times Sex) + (0.166 \times Anthropization) + (0.124 \times Education) + (0.145 \times Employment) \quad (11)$$

$$NH_{AHP} = (0.80 \times Seismic\ Hazard) + (0.15 \times Flooding) + (0.05 \times Rockfalls\ and\ Rockslides) \quad (12)$$

$$RC_{AHP} = (0.40 \times Access\ to\ Health\ Services) + (0.30 \times Access\ to\ Emergency\ Services) + (0.10 \times Access\ to\ Security\ Services) + (0.20 \times Access\ to\ Shelters) \quad (13)$$

where TV is territorial vulnerability, SV is Social vulnerability, NH is Natural Hazard, RC is Response Capacity, and WAHP is the weighting for each condition of territorial vulnerability.

As an illustration, we will present the results of the social vulnerability weighting. The levels and weight values of the conditioning factors have been defined and calculated in the **Table 4.** According to the degree of importance, age, gender, and anthropization appear to be the most important factors influencing social vulnerability according to the values which are respectively as follows: 0.331, 0.234 and 0.166, while the factors education and employment have the least influence on social vulnerability with values which are respectively: 0.124 and 0.145 **Table 4.** The following values: λmax = 05.05, CI = 0.0110 (1.10%) and CR = 0.005, means that the matrix in pairs is consistent (CR threshold <0.10) and can be used to assign weight criteria.



$$I_{vul} = \sum_{k} \omega_k \lambda_{i,j,k}$$

I_{vul} = *Index of vulnérability*

ω_k = *Weighting of each factor*

$\lambda_{i,j,k}$ =*Standardized value of the layer at the coordinates (i,j)*

k = Layer of information

Fig. 4 Principle of inter-factor weighting.

The vulnerability functions

Inter-factor weighting requires assigning a weight (ω) to each factor involved in the calculation of the overall fitness index (Caloz and Collet, 2011). In a context of spatial analysis, standardized criteria are weighted and then superimposed to achieve our objective in terms of global territorial vulnerability to hazards **Fig. 4**.

RESULTS AND DISCUSSIONS

The main result of our study is the map of territorial vulnerability (**Fig. 8)** that we obtained by combining the natural hazards, the social vulnerability, and the capacity response of the exposed system. Our calculations led to the hierarchization of 80 districts of the municipalities of Bordj El Bahri and El Marsa according to the different components of our vulnerability model. The most vulnerable district is the district with the higher value. This ranking allowed mapping four vulnerability classes (null, low, moderate, and high). We noticed that the vulnerability of our study area to natural hazards is moderate to high with values ranging from 28.65 to 43 at a standardized scale. The vulnerability to natural hazards in the south-western part of Bordj El Bahri municipality is quite high, particularly at the districts 36-58 (**Fig. 5).**

In general, the vulnerability is particularly caused by the exposure to seismic hazard since our zone is seismogenic and surrounded by several active and potential active faults**.** Regarding the flooding hazard which is moderate, it is mainly located in the western and south-western part of Bordj El Bahri because of the zone prone to flooding at the mouth of El Hamiz river. The hazard related to rockfalls is slow and may be observed in the northern part of El Marsa municipality.

The districts 7, 8, 9, 11, 12, 13, 14, and 15 of El Marsa **Fig. 5** face seismic hazard and rockfalls that make them highly vulnerable. From the map of social vulnerability **Fig. 6**, we notice that the related index ranges from 1.83 to 46.78 at a standardized scale; i.e. from low to moderate. This spatial variation of vulnerability results from the unbalanced distribution of the functions and urban services and the density of the built environment as well as its fragility and absence of conformity with respect to the required technical standards (building code and general rules of urban planning). We may also cite the fragility of the sociodemographic issues where some places are characterized by a very high urban fragility related to the population density among which the most vulnerable such as young and old people and the socio-urban context that may be precarious (unemployment and illiteracy). The extreme south of Bordj El Bahri is characterized by a quite strong vulnerability in terms of the social vulnerability, particularly in the districts 23, 24 and 25. This may be explained by the fragility of the built environment because nearly all the constructions of this zone are not compliant with the planning instruments and the building regulations such as the soil occupation index and the hold occupation index, in addition to the strong concentration of the urban issues. Regarding the municipality of El Marsa, we observe that the districts 12 and 15 are characterized by a fairly high social vulnerability with respect to the other districts because of the very high density rate of the built environment and the high concentration of urban installations.

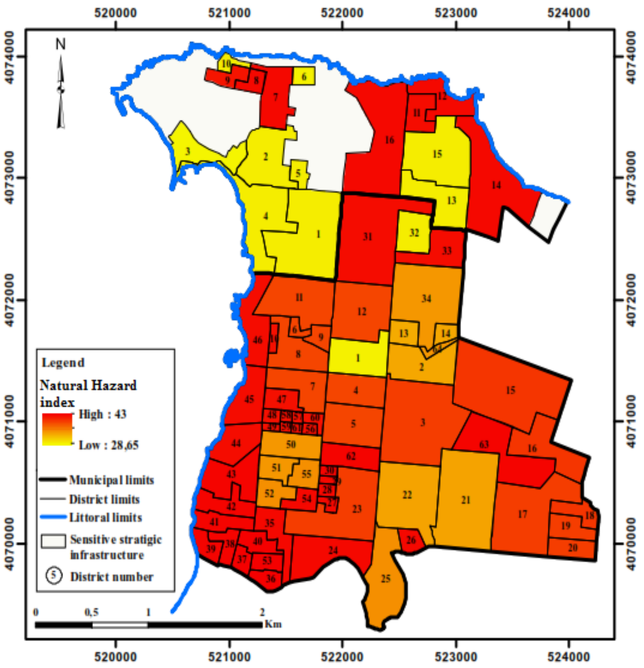


Fig.5 Index of natural hazards exposure

The simulation of the vulnerability related to the response capacity of the municipalities of Bordj El Bahri and El Marsa is illustrated in **"Fig.7".**Broadly speaking, the responsiveness in our study area is fairly good to good since we found results ranging from 29,31 and 59,99 at a standardized scale. This is because of the presence, in the nearby area, of services related to the crisis such as the civil protection, the health equipment, the security services, wastelands, green areas, etc. **"Fig.7"** shows that the districts 1-8 of El Marsa present the lower indexes of responsiveness in the case of the occurrence of a major natural hazard because of the absence of open spaces and services (emergency and shelters), unlike the response capacity of the districts 1-5 of Bordj El Bahri which is high due to the proximity of emergency services and the presence of several shelters, open and green spaces.

To determine the vulnerability of the municipalities of Bordj El Bahri and El Marsa to major natural hazards, we superimposed standardized and weighted layers. The map of the global vulnerability **"Fig.8"** represents in every detail the final result expressed through an index that takes into account all the variables that we retained. As expected, the higher values of the vulnerability index are located in the western part of Bordj El Bahri. This is not surprising because of the high values observed in different factors such as those related to the capacity response (remoteness of the hospital, absence of shelters), the factors related to the social vulnerability (high rate of unemployment, illiteracy, high densityof the population and built environment) as well as the exposure to hazards such as seismic hazard and liquefaction around the banks of El Hamiz river in addition to the flooding to which El Marsa municipality is facing at the mouth of El Hamiz river, and the marine transgression along the eastern part of the Algiers bay that belongs to this municipality. The districts 1-5 of the municipality of Bordj El Bahri present the lowest levels of the vulnerability as reflected by the low vulnerability factors that we obtained and may still suffer losses due to earthquakes.

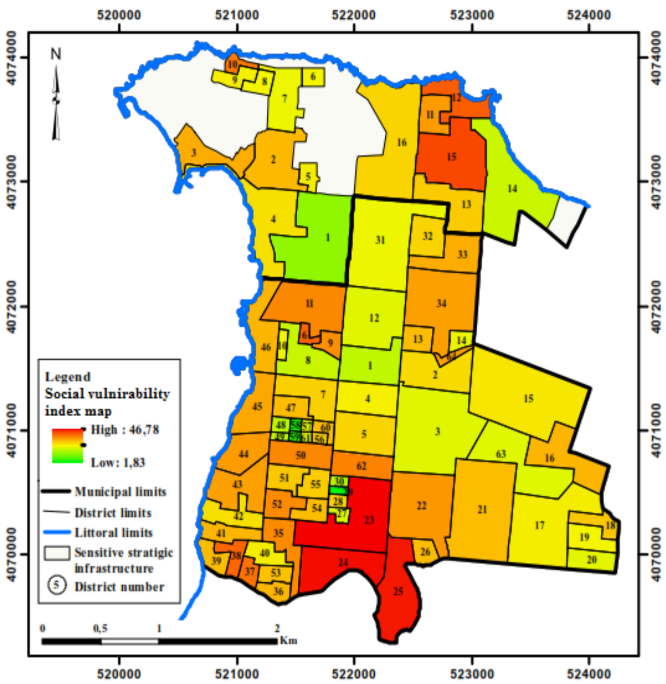


Fig. 6 Index of the Social Vulnerability

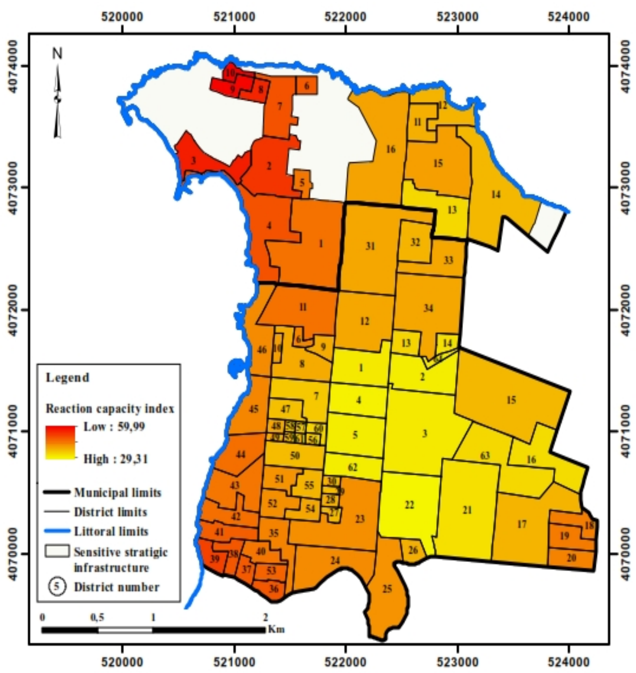


Fig.7 Index of the response capacity

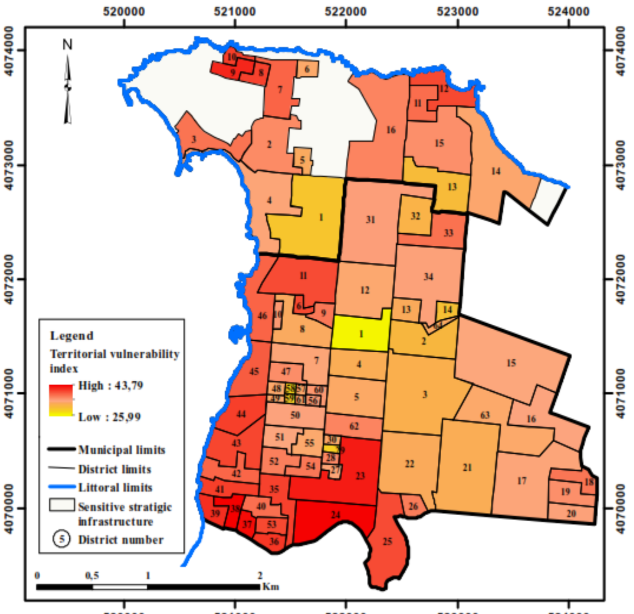


Fig. 8 Index of the territorial vulnerability

Map of the territorial vulnerability can be used as a decision-making tool to define appropriate actions to be implemented at the local level to minimize damage and loss of life and property. It is also necessary to point out that damage scenarios that represent risk prediction tools are often developed on the basis of the physical characteristics of the hazard (amplitude, intensity, probability of occurrence, etc.), without taking social vulnerability and ability to respond. In this regard, the results highlight the importance of assessing the interactions between human activities (social and urban systems) and natural hazards, as vulnerable populations highly exposed to natural hazards must have the capacity to react and adapt to confront a dangerous situation caused by a natural disaster. In this context, the indicators and maps developed in this work could help local and regional authorities to launch strategies and policies for preventive planning to reduce territorial vulnerability in a location given.

Limitations of the method

The method that we used calls for some comments. It responds to the needs of management and decision making by alternating the holistic and analytical view, and by providing a visual synthesis of the statistical and spatial correlations at the origin of the interactions that create the natural risk and vulnerability. Another limitation comes from the quality of data and some approximations performed. We have seen that the quality of data inferred from the 2008 census was called into question, but the internal random error of less than 2.5% is minimal compared to the clear oppositions that we highlighted. This affects the result or more precisely the global index of vulnerability. Finally, the visual efficiency sought by the superimposition of spatialized information is detrimental to the consideration of important vulnerability factors because of the lack of information. We may cite as example the factor of accessibility, the expertise of buildings, which were approximated. However, the use of a relative estimate of vulnerability and the reduction of variables taken into account favors the analysis of the underlying situations.

CONCLUSION

In our study, the assessment model of the territorial vulnerability based on a GIS was used to assess the vulnerability of two municipalities of the wilaya of Algiers to major natural hazards. Three parameters: natural hazard exposure, social vulnérability and responsiveness of exposed system were elaborated and classified to calculate the vulnerability indexes. The spatial distribution of the vulnerability degrees of the municipalities of Bordj El Bahri and El Marsa to major natural hazards is generally weak to moderate with indexes ranging from 29 to 43 at a standardized scale. They allow characterizing three classes of vulnerability: very low (0-15), low (15-30) and moderate (30-45). The low-vulnerability areas almost occupy all the surface of the study area whereas the high indexes are located in the northwestern part of that area, particularly at El Marsa and the western and southwestern parts of Bordj El Bahri where the rates of the factors of vulnerability, in terms of hazard exposure, social vulnerability weaknesses and weak capacity response, are high. The simulation results that we obtained highlight all the available factors for assessing the vulnerability of the municipalities of Bordj El Bahri and El Marsa to major hazards. They show us the respective importance of both localities in a multidimensional structure that takes into consideration the correlation between the degree of hazard exposure, the weaknesses of the urban issues with respect to hazards and the responsiveness of the exposed system during the occurrence of a natural hazard. This spatialized approach of the vulnerability allows the stakeholders to ensure a sustainable management of the territory. It constitutes a decision-making aid in terms of planning and land use by identifying the most threatened areas to natural hazards.

There is a great need to integrate territorial vulnerability into sustainable urban planning. The traditional planning paradigm emphasizes physical vulnerability and limits itself to exposure to hazards in contrast to territorial vulnerability, which is based on the assumption that disasters are socially constructed. In conclusion, the methodology presented in our work aims to develop a procedure based on a socio-urban analysis of the Algerian municipalities, aimed at identifying and characterising the most vulnerable areas of the territory studied. The main results of this research focus on a significant selection of social, economic, urban, physical and territorial variables to assess the overall territorial vulnerability index. Visualization of territorial vulnerability maps provides an important database to understand spatial variation, dimensions, shapes and factors. However, this study focuses on a framework of analysis that aims to understand the spatial relationship between social vulnerability, exposure to natural hazards and the response capacity of the urban system, by highlighting a detailed analysis on a scale (district) to design a decision-making tool to reduce vulnerabilities to natural disasters and spatialize the necessary actions and measures in this area. The review of the relevant scientific literature reveals that there is an improvement and great advance in knowledge, conceptual frameworks, indicators and different methods that contribute to the characterization and evaluation of vulnerability. Although there is no consensus on different evaluation methods because each approach offers these particular advantages over its specific assumptions and context (Khan, 2012).

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