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Identifying seismic vulnerability hotspots in Bucharest

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ABSTRACT

Measuring seismic vulnerability is a complex and valuable endeavor. It allows us to focus resources where they are critically needed. In this research a variety of data was used to identify the most vulnerable areas in Bucharest in case of an earthquake. Socio-economic data from censuses in 2002 and 2011 were used to generate an overall spatial vulnerability index, while other variables such as earthquake scenarios and distance to resilience-enhancing points in space (e.g., parks, fire stations, etc.) helped to fine-tune the analysis and offered a comprehensive picture of where vulnerability hotspots can be found in an urban environment. The top three most vulnerable hotspots are analyzed and two underlying reasons for their vulnerability are proposed and discussed in more detail: education and connectedness. We applied uncertainty and sensitivity analyses to assess the stability of the results for the vulnerability hotspots. The general outcome of the research is an increase in the overall socio-economic vulnerability in the city in spite of the upward economic trend in the period of time under analysis. Some key challenges about the origins of vulnerability are raised.

1. Introduction

The way social vulnerability is understood and studied has undergone significant changes in the last decade (Chang, Yip, Jong, Chaster, & Lowcock, 2015). Greater attention has been given to resilience, social vulnerability perspectives have been extended, and new measurement methods at the community scale have grown in number. Changes have involved debating how social vulnerability is defined, what metrics should be used and how reliable they are in different contexts, and if resilience is separate from vulnerability or a part of it. From approaches that tended to exclude socioeconomic indicators to the current one which quantifies vulnerability through population characteristics or determines two facets of vulnerability – build construction and socio-economic, the methodological praxis has been diversified. It outlines the availability of indicators, whilst restrictions appear in limited use of assessing resilience, coupled with sporadic use of sensitivity and uncertainty analysis (Beccari, 2016).

Vulnerability meaning remains biased to different views from various areas of research, from the biophysical to social sciences (see Armaş & Gavriş, 2013), as Birkmann (2006) systematized more than 25 competing definitions. The working definition of vulnerability used in this study is closer to the view of social scientists, defined as a set of socio-economic factors improving people's ability to cope with unexpected hazard events. This approach also adheres to the principal tenets (Cutter, Burton, & Emrich, 2010): vulnerability as a social condition, and the focus on a particular place or region.

Despite variation among different approaches, there is wide consensus on the importance of vulnerability to the outcomes of a disaster, especially indicators of social vulnerability becoming increasing helpful to mitigation policies. Risk is the combination between the likelihood and the consequences of a hazard materializing. Part of the risk definition, social vulnerability shapes the understanding of capacity to adapt and respond to hazards through the population's characteristics. If areas of high vulnerability cluster together, then enhanced actions may be customized to improve policies and prepare individuals and communities. Together, policies from these areas can stimulate areas with lower vulnerability to focus on individual measures and trigger governmental interventions (Koks, Jongman, Husby, & Botzen, 2015), while pilot studies provide lessons as a condition to prepare individuals to act alongside administration intervention systems, as well as to

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empower communities to become more place-aware (Armaş & Gavriş, 2016). Overall, social vulnerability "*possesses the capacity to respond to environmental changes and disasters that affect social systems, and can remind governmental agencies, the private sector and residents to found developmental strategies on social conditions — particularly in the most vulnerable places*" (Lee, 2014, p. 31).

For the past thirty years there have been significant efforts to measure and localize vulnerability (e.g.: Alexander, 1993, 1997; Armaş, 2008, 2012; Armaş & Gavriş, 2013; Jackson, 2006; Bolin & Stanford, 1999; Varley, 1994; Wisner, 1998). Despite these and other issues related to social vulnerability measurements (Cutter, Boruff, & Shirley, 2003), indicators of socio-economic vulnerability evolved based on the hazards-of-place model (Cutter, 1996), being generally used to assess the relative vulnerability of places. Advancements in the way scientists understand and operationalize vulnerability allowed refinements related to spatial scale (Frazier, Thompson, & Dezzani, 2014; Nelson, Abkowitz, & Camp, 2015; Schmidtlein, Deutsch, Piegorsch, & Cutter, 2008), temporal changes (Cutter & Finch, 2008), uncertainty (Jones & Andrey, 2007; Tate, 2012), institutions (Council, 2012), critical application to different contexts (Holand & Lujala, 2013; Kuhlicke, Scolobig, Tapsell, Steinführer, & De Marchi, 2011; Rufat, Tate, Burton, & Maroof, 2015), similarity (Chang et al., 2015) and facilitated collaboration between researchers and local stakeholders for better understanding (Oulahen, Mortsch, Tang, & Harford, 2015). Validating indicators was also important for some studies (Brooks, Adger, & Kelly, 2005; Fekete, 2009; Ge et al., 2013) leading to the selection of other methodologies (Armaş & Gavriş, 2013; Zebardast, 2013) that advanced the understanding of social vulnerability. What research has discovered is that vulnerability is dynamic, affected by constant evolution of communities and people within space and contexts (Kuhlicke et al., 2011), which means that context is multifaced (Rufat et al., 2015) and dependent on specific hazard type.

The need to streamline and provide comparable and easy to use results has led to the development of vulnerability indicators. Generally, these provide some form of aggregation of underlying factors, including hazard exposure. Factor selection varies from deductive approaches based on theoretical understanding to inductive ones based on statistical relationships (Adger, Brooks, Kelly, Bentham, & Eriksen, 2004). To obtain these indicators, different approaches emerged: cross exposure with selected socio-economic parameters (Peduzzi, Dao, Herold, & Mouton, 2009); selected demographic variables pertaining to fragility, socio-economic conditions and region (Fekete, 2009); Cutter et al. (2010) analyze social, economic, institutional, infrastructure, and community capacities; Brooks et al. (2005) also use expert opinion; Flanagan, Gregory, Hallisey, Heitgerd, and Lewis (2011) and Armaş and Gavriş (2013) use census data; Hahn, Riederer, and Foster (2009) aggregate socio-demographics, livelihoods, social networks, health, food and water security, natural disasters and climate variability; Rygel, O'Sullivan, and Yarnal (2006) apply Pareto ranking to the factors as opposed to weighting them; while Pelling (2012) uses city population, annual urban population growth rate, proportion below the poverty line, and Human Development Index rank. However, research using vulnerability indicators faces challenges, particularly towards conceptualizing factor interactions and their evidence (Eriksen & Kelly, 2007).

In our research we build on these efforts with the aim of spatially evaluating socio-economic vulnerability to hazards, particularly earthquakes, in Bucharest, the capital city of Romania (Fig. 1). The rationale behind our research is that quantifying social vulnerability can help comprehensive understanding of the dimensions on which it emerges. Given that natural hazards are commonly unavoidable, it becomes crucial to identify where, in time and space, vulnerability develops and how this can inform resilience-building decisions.

This research uses selected socio-economic census data in conjunction with earthquake scenarios and distance analyses to locate and compare the most vulnerable hotspots in Bucharest. Spatial distance analysis offers added insights into increased vulnerability locations, out of the range of resilience-building determinants (top schools and hospitals, or parks and major roads). While some of these elements work to improve the factors underlying socio-economic vulnerability (e.g., a good school nearby will increase education), the proximity of others (parks, fire stations) enhances resilience in post-disaster situations. The effect is the same: spatial proximity of certain elements increases resilience. It is under this assumption and through hazard specific scenarios that the research in this paper aims to identify vulnerable areas within an urban environment.

2. Study area

Bucharest is one the most endangered capitals in the world due to seismic hazard, as all (as far as we know) global and regional hazard studies such as Giardini, Grünthal, Shedlock, and Zhang (2003, 2013) or Jiménez, Giardini, Grünthal, and Working Group (2001) reveal, and also the reality of the 20th century proved. It can also be considered the most endangered capital in the European Union. During the 1940 and 1977 earthquakes (with moment-magnitudes Mw of 7.7 and 7.4) that occurred in the Vrancea Intermediate-Depth Source (Fig. 2), 1564 people were killed in Bucharest, mostly due to the collapse of medium and high-rise buildings. Most damage was in the city center, where many constructions built without seismic design code considerations (prior to 1940) and with poor construction quality were and still are located. As 2011 statistics show, nowadays in Bucharest there are more than 31,430 buildings belonging to the precode era. Experts employed by the Bucharest City Hall individually evaluated 759 vulnerable buildings (PMB, 2016) and considered 357 as being in the seismic risk class I (meaning that they could collapse from any event similar to the control period earthquake). The 1977 earthquake also proved that some newer buildings can also be severely affected, due to design and construction errors.

Although located more than 80 km epicentral distance from the Vrancea Seismic Source, significant peak ground acceleration (PGA) values, greater than 0.2 g, can occur in Bucharest. A recent seismic microzonation study (Mărmureanu, Cioflan, & Mărmureanu, 2010) shows that for the maximum predicted Vrancea earthquake (with Mw 7.8, at 150 km depth), PGA values from 0.22 g up to 0.3 g could be recorded at surface. As this study shows, along the Dambovița River the PGA values can be expected to be smaller; however, we consider that the geological datasets for the city area still don't provide a clear picture of what zonal differences could be (there are few boreholes with depth > 100 m available for explaining the propagation from bedrock to surface, in an area with deep sedimentary layers, and few strong motion recordings). There is also a significant distribution variation to be expected from one event to another, depending on slight modifications in earthquake parameters - real recordings from the 1986, 1990 or 2004 moderate magnitude earthquakes revealed different patterns in terms of PGA distribution (Pavel, Văcăreanu, Aldea, & Arion, 2013).

Bucharest has a population of about two million but its higher pace of development — compared to the rest of the country — both during communism and post 1990 puts the figure closer to 2.3–2.4 million inhabitants.[1] This makes the risk even higher (Armaş & Gavriş, 2016).

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[1] Informal talks to specialists and authorities confirm these, despite not being captured into statistical censuses.