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Identifying optimal locations for mobile first aid facilities in Bucharest, accounting for seismic risk

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Abstract. In case of a major earthquake in the Vrancea area, Bucharest can be significantly affected (as it happened in 1940 and 1977). As highlighted by these events, the need for establishing mobile first aid facilities close to affected areas (deployment of medical containers or mobile hospitals) is expected to be of high importance for saving lives. In this research we identify the need of such facilities and the favorable locations, considering multiple earthquake scenarios. Our methodology is based on multicriteria analysis in which we use the SMCE module of the ILWIS geospatial program and take into account three indicators: (i) the estimated losses in terms of affected residential buildings and occupants, calculated for 3 earthquake scenarios, (ii) distances from buildings with high seismic risk levels (categories I and II) and from important traffic routes, and (iii) road network connectivity loss after a major earthquake. The results identified the central and peripheral area as having complex issues and the need for future analyzes at the neighborhood level.

Keywords: *first aid, emergency management, earthquake, Bucharest, disaster risk*

1. INTRODUCTION

The city of Bucharest is probably **Europe's highest seismic risk capital city** (Pavel and Vacareanu, 2016; Toma-Danila and Armas, 2017). Previous earthquake experiences (such as the one in the Vrancea Area on 10 Nov 1940 with moment-magnitude Mw = 7.7 or 4 March 1977 with Mw = 7.4) and the current situation support this statement (Fig. 1). A first aspect is represented by the **vulnerability of buildings** – currently 349 buildings have been examined and classified in seismic risk class I, out of a total of 856 examined buildings (PMB, 2020). Beside these, statistical data from the 2011 National Census indicate that there are currently **many more old buildings that could be highly vulnerable**: around 10% of the total residential buildings were built before 1963, a period in which there were no compulsory seismic design codes in Romania.

Bucharest is the most important industrial, commercial and administrative center in Romania and the city with the highest number of inhabitants – there were 2,112,483 inhabitants in 2018 (INS, 2018). Times have changed (compared at least with 1977) **road traffic could pose a significant additional risk in disaster situations**. There are over 1.2 million registered vehicles (INS, 2018). A study by TomTom (2019) places Bucharest in the 4th place in Europe (1st in EU and 14th in the world) in terms of road congestion level. That is why we also felt important to take this factor into account in our analysis.

2. OBJECTIVE AND METHOD

The objective of this study is to identify the need and optimal locations for first aid facilities in case of seismic disaster at full Bucharest city level, by applying the multicriteria method. These facilities must be able first of all to accommodate specific containers with the necessary equipment for first aid. The analysis took into account the intervention times in case of disaster, parking lots of over 1000 sqm as potential favorable locations, the seismic vulnerability of the built space, and the socio-economic and environmental vulnerabilities.

A new methodology was used to **identify the distribution of emergency response times and areas that may become difficult to access** in major earthquake conditions in Bucharest, as defined in Toma-Danila (2018) and Toma-Danila et al. (2020). This methodology is integrated in a toolbox for ArcGis called Network-risk, which allows the calculation of intervention times by modeling the implications of an earthquake on the road network: directly, taking into account the probability of collapse of structures and blocking road segments, as well as indirectly, taking into account the redistribution of traffic. The variability of possible situations is analyzed using a Monte Carlo simulation, including considerations regarding typical traffic on a Monday at 2 AM, 8 AM and 6 PM. The considered locations of the emergency response crews are those of the emergency hospitals (with an emphasis on category I emergency hospitals) and of the fire brigades. The road network data used for Bucharest comes from OpenStreetMap, as of January 2016. In total, 50,412 individual road segments are individualized and used.

As a result of this approach, **the final map of qualitative assessments of potentially inaccessible road areas in case of earthquake** for the 3 traffic scenarios and for a combination of values obtained from the worst possible scenarios and random scenarios selected by the Monte Carlo method is included in the location analysis.

The site analysis is limited to a general identification of needs at city level in relation to the areas suitable for this purpose, depending on the requirements of providing first aid for disasters. To this end, the **parking lots with an area equal to or larger than 1000 sqm**, shown in *Figure 2*, were selected at city level.

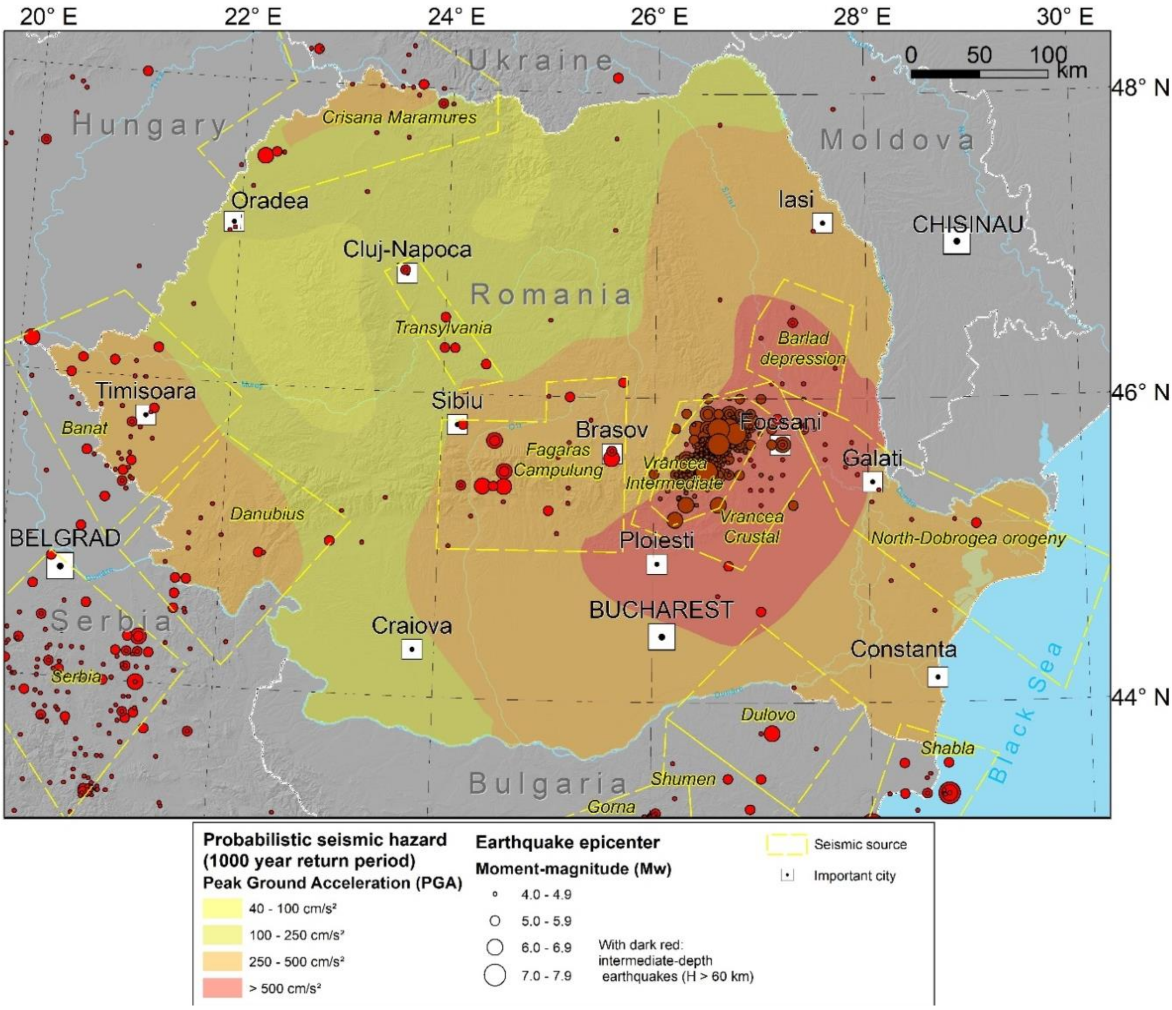

Fig. 1 Earthquakes in Romania and the main seismic sources (according to the Bigsees Project, 2016), as well as the seismic hazard (according to the Ro-Risk Project, 2017) calculated probabilistically, for a 1000 year return period

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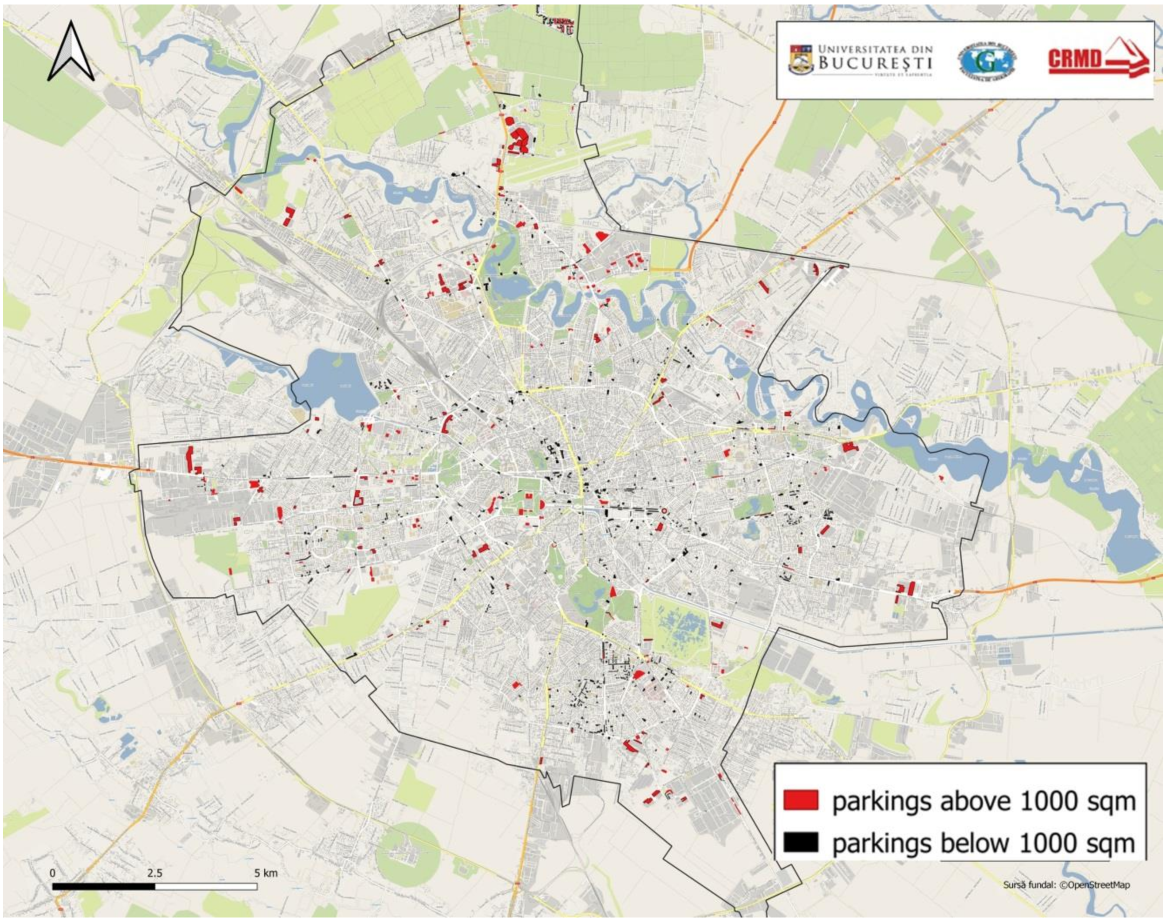

Fig. 2 Map of parking lots with an area equal to or greater than 1000 sqm

Within the administrative limit of the city of Bucharest there are 242 parking lots of over 1000 sqm. However, these locations must be studied individually according to the criteria of safety and accessibility in case of disaster, and also to the first aid need in the area. Many of these car parks meet the requirements of the spatial analysis, but a detailed assessment indicates that they serve blocks of flats, being overcrowded and vulnerable in the event of a building collapse.

The categories of car parks identified in Bucharest are: **Commercial** – private car parks belonging to shopping centers (including street markets, malls, supermarkets and hypermarkets), **Public** – public car parks (free-of-charge or paid), **Public institutions** – the private car parks of public institutions, **Private** – private parking belonging to companies, **Residential** – private parking for the residents of residential neighborhoods, **Depots** – private parking of the Bucharest Transport Company (including bus bases), **Military Institution** – parking within the Land Forces bases, **Airport** – parking at Baneasa Airport, and **Embassy** – the private parking of the US Embassy.

The general analysis of the selected locations shows an uneven distribution, different from one sector to another, so most parking categories are found in sector 1 (8 categories), and the least in sector 3 (4 categories).

The most suitable locations for the purpose of the study are commercial parking lots, which are quite large and the number of cars parked long-term is low. They are also not surrounded by tall buildings, which could collapse in a strong earthquake, reducing the usable area of the car park by 20% of the volume of the collapsed building. Also suitable would be the parking lots belonging to the Bucharest Transport Company, because they occupy extensive areas, usually located away from tall buildings.

An **overall analysis of favorable large car parking areas** in relationship to the 2011 census districts was made, taking into consideration **the environmental conditions, the seismic hazard, the overall construction vulnerability of the**

buildings, the social and economic conditions and vulnerabilities, the estimated risk calculations, the flood risk map of the city in the case of a dam rupture scenario (e.g., Armaş, 2012; Armaş and Gavriş, 2013; Armaş et al., 2016, 2017; Gogoaşe Nistoran et al., 2019; Zaharia et al., 2016)**, and the risk analysis in different earthquake scenarios in Bucharest**.

In the analysis of the relationship between the possible container locations and the site-specific conditions, the following additional data was included:

- **areas qualitatively assessed in terms of the vulnerability of response times** in the event of an earthquake, for intervention crews (ambulances and firefighters), as well as areas that may become inaccessible (likely to become so). For this analysis, the locations of all police stations, hospitals, firefighters, and ambulance stations in the city were processed.

The main focus of the analysis was on the difficulty of accessibility in post-earthquake conditions for emergency services – ambulances, firefighters or SMURD crews, which are major players in reducing the number of victims and thus the seismic risk.

- **buildings in seismic risk class I** (according to the official list from the City Hall from January 2016), in order not to jeopardize the access to the location of the container locations or even to endanger their positioning through major risk of collapse. At the same time, it was taken into account that the selection of locations should be in the vicinity of areas with a high density of these buildings with major seismic risk.
- **estimates of damage at the census unit level** (with cut-outs for areas without residential buildings), made with the help of Seisdaro System – the SELENA software based module (Toma-Danila et al., 2018) using exposure data from 2011 and two representative earthquake scenarios: 1977, and the Bucharest microzonation map for a strongest possible earthquake scenario for Vrancea Area (Marmureanu et al., 2010). Averaged estimates for completely affected buildings and worst-case scenario number of deaths and severe injuries (Toma-Danila and Armas, 2017) were considered.

3. MULTICRITERIAL ANALYSIS IN IDENTIFYING THE FAVORABLE/ UNFAVORABLE POTENTIAL OF LOCATION POINTS

The **multicriteria spatial analysis module (SMCE) of the ILWIS geospatial program** was used in the analysis of the relationship between generic location areas at city level, depending on the dimensional criteria and environmental conditions. This multicriteria analysis involves the use of data (qualitative or quantitative) to saturate the selected analysis indicators (criteria) and combine them according to their importance for the proposed aim. The purpose of our analysis was to scan at city level and identify the favorable/ unfavorable locations for first aid facilities, depending on major vulnerability and risk criteria. However, the resulting image must be interpreted considering the needs of the city, respectively: **the unfavorable areas for the location are those where the demand for first aid points is high**. This is because these areas are hot spots of seismic risk, which will involve collapsed buildings and human casualties.

As a methodology, the used data for each indicator **highlights the favorable or unfavorable areas for the site** and the combination is made using a criteria tree that weighs the importance of each indicator (criterion) in the final result (final map of unfavorable/favorable identified sites).

The multicriteria tree was designed on three criteria/indicators:

1. *Traffic vulnerability and probability of blocking/isolation of certain areas*
2. *Analysis of distances from buildings with seismic risk I and II and from important traffic arteries*
3. *The potential direct seismic losses (residential buildings and population), calculated based on two earthquake scenarios.*

The traffic vulnerability indicator is composed of the vulnerability index according to the intervention times for ambulances and firefighters and the index of obstructed areas. The response time index is composed on a scale from 1 to 5, where *1 means low vulnerability* – usually reached in a maximum of 10 minutes to the intervention, both by ambulance and firefighters – the average of

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3 scenarios of which 1 without traffic, and *5 is very vulnerable* – it cannot be reached in less than 25 minutes (ambulances and firefighters). The probability of being blocked in traffic highlights areas that are difficult to access by the intervention crews, blocked mainly due to collapsed seismic risk class I buildings (20% to 90%). The analysis took into account the distance index from these areas with a high probability of remaining blocked and isolated in the case of the 3 earthquake scenarios.

The distance indicator contains as a *favorable aspect* the location of the containers in the proximity of the main arteries (the accessibility criterion), and as an *unfavorable aspect* for the location, the proximity to the buildings with seismic risk. Distances from buildings at risk of collapse were interpreted as an impediment to the establishment of sites. A distance of *500 m* is the minimum from the respective buildings to make the location favorable, and the distance from the large arteries was interpreted as a benefit index (the longer the distance, the harder it is to reach). The empty weighting method was used, setting a maximum limit of *500 m* for favorability.

The potential direct seismic losses are represented by the average vulnerability of buildings at city level and by the maximum percentage of population loss (dead and seriously injured), in the case of the two earthquake scenarios.

As a normalization, for the indices that make up indicators 1 (*Traffic Vulnerability*) and 3 (*Potential direct seismic losses*), benefit normalization was used at intervals, to highlight the finest differences in the data string of the unfavorable footprint for locations.

The weighting at the level of the 3 indicators was direct, giving more importance to the blockage of some arteries and the isolation of some areas in the city due to the collapse of buildings for the *traffic indicator*, the proximity of buildings with eminent risk of collapse in case of the *distance indicator* and the percentage of human casualties in the total population of the constituency in the case of *indicator 3*.

When agglutinating the indicators in the final map of unfavourability/favorability of each location, the 3 indicators were given equal weights.

Parks, vacant, agricultural, and unbuilt lands were removed from the analysis and appear in white in the final map, but during a later analysis, some of them may come into question as possible locations, except for those along the Dâmbovița river, which are at risk of flooding.

The parking lots with over 1000 sqm are shown in black on the map in *Figure 3* and the limits of the 2011 constituencies have been shown for better localization. Since the legend was set so that high values (towards red) indicate unfavourability in locations, it is found that the central area is the most restrictive from this point of view, presenting the possibility of traffic jams and isolation of areas, having a high vulnerability of buildings and a high density of buildings framed with seismic risk, generating possible loss of life in the event of a disaster. However, this is the area with the greatest need for such first aid points. Diametrically opposite, the most favorable areas of location prove to be those in blue on the map, which approach no problems related to the selected previously presented indicators and their processing. This result underlines even more obviously the need for localized, detailed analysis, with updated field data for each type of situation.

4. RESULTS

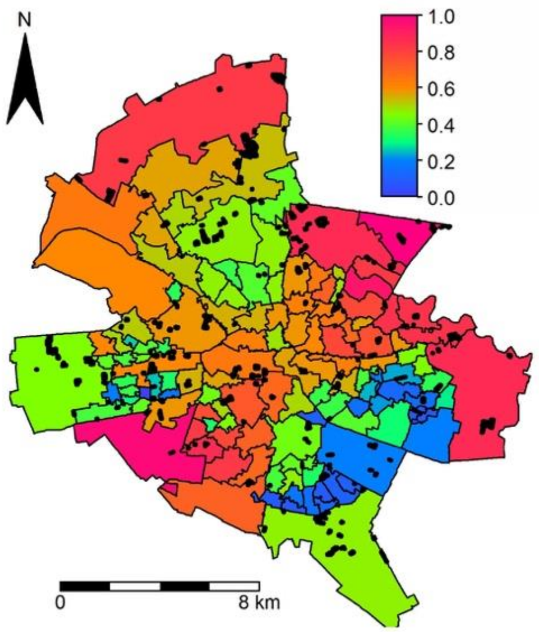

Fig. 3 The overall building vulnerability

The average overall building vulnerability (1 = total destruction) and the distribution of spaces representing parking lots at city level are shown in *Figure 3.* The problem of the central area, but also of the peripheral one is observed, where neighborhoods such as Bucureștii Noi, Străulești, Rahova, and Ferentari, characterized by single-family suburban houses embedded in the city structure, have a high seismic vulnerability, doubled by lack of favorable locations to first aid points.

The number of houses in each census district is shown in *Figure 4*, in relation to the distribution of car parks (white areas represent areas without residential buildings, including parks and vacant land). To be observed is the concentration of a maximum number of houses in the peripheral areas, embedded in the urban fabric, but keeping its rural character. The high density of houses, delimited by narrow streets, is doubled by the lack of open spaces favorable to the locations of first aid points.

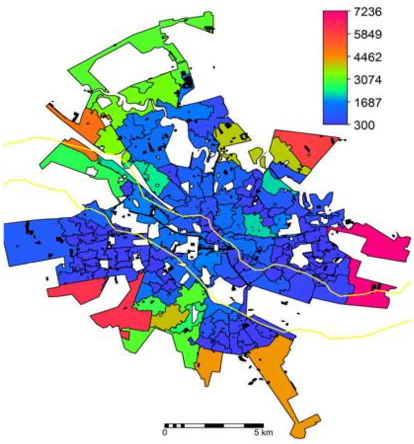

Fig. 4 Total number of houses

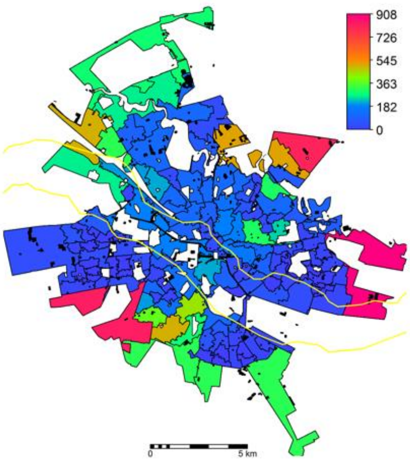

Fig. 5 Number of houses estimated to be severely damaged

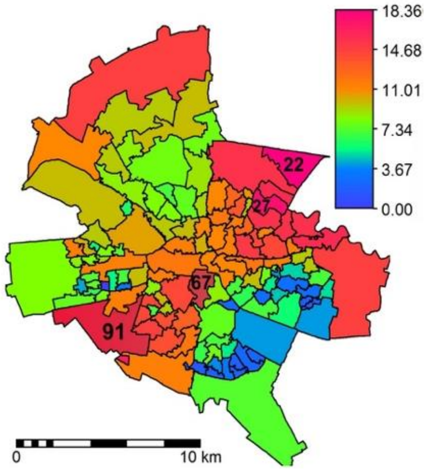

Fig. 6 Total loss %

The number of houses severely damaged in the event of the strongest possible earthquake is shown in *Figure 5*, in relation to potential parking lots. Of course, disaggregation of buildings per height regime provides a more representative image of the potential need for first-aid assistance, but this is reflected in *Figure 6*.

In *Figure 6* there is the maximum losses among the overall number of buildings according to the 2011 census districts, shown as a percentage of the total buildings in the district. There is a concentration of these losses in the same peripheral areas previously identified as part of the peri-urban rural fabric embedded in the city. In these areas, cheap houses, made of brick or even mudbrick, predominate. They are crowded in family compounds, in almost non-existent yards. They line up on narrow streets, sometimes only 2-3 m wide, in many situations unpaved and without sewage systems.

In this landscape with a predominantly rural imprint of buildings, residential blocks of flats are built from place to place, with 5 to 8 floors, without adequate spaces between buildings, delimited by clogged streets, sometimes without sewers. We do not have information about the observance of construction norms in these residential complexes but their height enters the spectrum of the seismic vulnerability of the city (buildings with over 4 floors).

It is often difficult for fire trucks to enter the space between the blocks that form these residential complexes, with alleys much undersized to maximize profits and devoid of green spaces.

At city level, there are 4 constituencies with a maximum overall building vulnerability, lined up in a NE-SW direction through the entire city: 91, 67, 27 and 22 in *Figure 6*.

These districts include both the situation of cheap houses on the outskirts of the city, and the area of Cosbuc Square – Carol Park, with historic brick buildings, in a state of advanced degradation, sometimes even in ruins.

The estimated number of people severely injured and killed in the event of the maximum possible earthquake scenario is shown in *Figure 7* in relation to the positioning of car parks and the flood mask.

The share of the affected population from the total population of the constituency in a maximum possible earthquake scenario and in relation to all parking lots in the city is shown in *Figure 8*.

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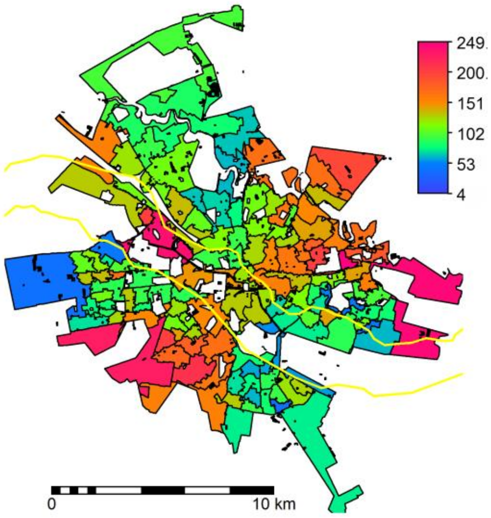

Fig. 7 Total number of severely injured and deceased, for the maximum possible earthquake scenario

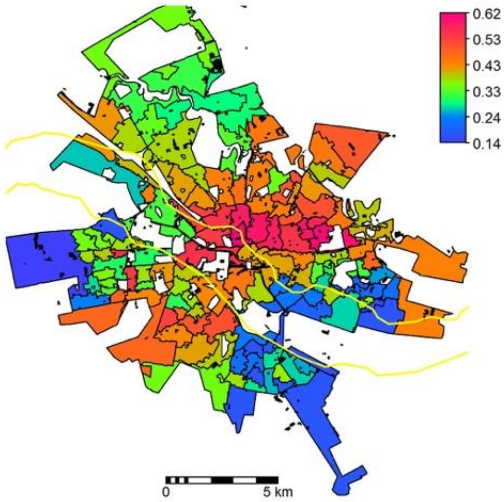

Fig. 8 The share of the severely injured and deceased in the total population of the constituency, for the maximum possible earthquake scenario.

It is observed that the central and peripheral areas can be the most affected. The absolute number of severely injured and deceased estimated in Figure 7 represents more than half of the resident population in the respective constituencies. Being predominantly residential areas, a difference will appear depending on the time of the catastrophe, with a maximum of affected population in the evening/night scenario, when the inhabitants willbe mostly at home (the worst-case scenario that we used).

Considering the visual interpretation of the spatial results, there is a concentration of buildings with seismic risk 1 in the historic center, along with a small number of parking lots that meet the condition of placing the containers. At the same time, the high density of constructions, many of them historical, is not completed by the presence of green spaces with wide openings, especially outside the area at risk of flooding in the Dâmbovița meadow.

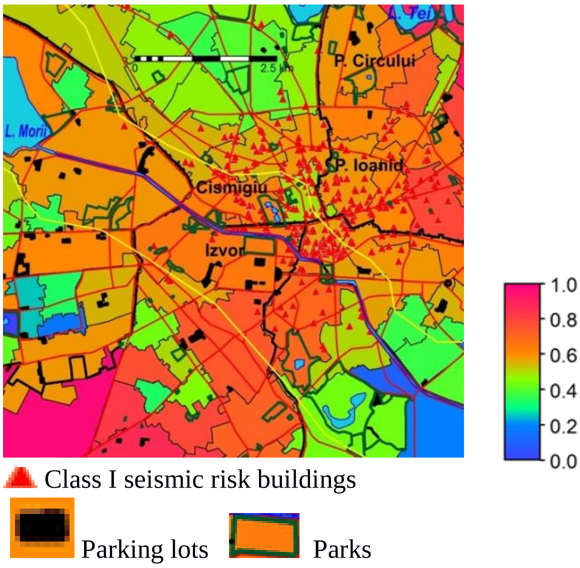

Fig. 9 Vulnerability map detail

The map detail (*Figure 9*) for the city center, shows the high and very high vulnerability of the buildings, the high population vulnerability and the lack of optimal spaces for the location of first aid points.

5. CONCLUSIONS

In this analysis, the most important selection criteria are based primarily on the proximity of the areas with many buildings potentially affected by a major earthquake (although taking into account only class I seismic risk buildings is not sufficient – in reality there being many more vulnerable buildings not yet seismically examined, many of them also in the central area of the city). Another criteria was to maintain road accessibility in the event of an earthquake (connection with the rest of the city) and also to consider the available space (1000 sqm) for the installation of specific first aid points for emergencies.

Even though during previous major earthquakes problems in Bucharest appeared in the city center due to the collapse of buildings of moderate and

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medium height, and road traffic was not significantly affected, since the number of vehicles was not high, we believe that this situation could be totally different nowadays.

The city center can be considered as presenting the highest risk, due to the dysfunctions of the road networks. Even with the Colțea Hospital and the Mihai Vodă Fire Department present in this area, the many small streets and many old buildings significantly limit the choices for alternate routes.

The process of identifying the needs of the location of first aid points in emergency situations in Bucharest will have to be continued through a neighborhood by neighborhood analysis and will involve the application of decisional analysis to choose the optimal locations based on a participatory method, by weighting all the interests and needs of those involved.

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