Assessing the earthquake systemic vulnerability of the urban centres in the South-East region of Romania. The tale of Galați and Brăila Cities, Romania

Andra-Cosmina Albulescu, Adrian Grozavu, Daniela Larion and Gina Burghiu

Faculty of Geography and Geology, Department of Geography, Alexandru Ioan Cuza University, Iasi, Romania

ABSTRACT
Earthquakes are one of the most destructive natural phenomena in the world, their impact being of particular severity in urban areas. Failures relating to proper allocation of resources, to the identification of optimal routes between the affected urban areas and relief centres, and to the mitigation of potential earthquake-triggered destructive phenomena emerge as systemic vulnerability sources. This paper aims to assess the seismic systemic vulnerability of the 6 administrative centres in the South-East region of Romania, by proposing a weighted composite index (Earthquake Vulnerability Index, ESVI) that integrates indicators referring to the accessibility of emergency services centres, the capacity of the local medical infrastructure and secondary danger sources. The validation of ESVI relies on Sensitivity Analysis and Multi-Criteria Decision-Making (MCDM) methods. Moreover, in order to illustrate the utility of an assessment of this type, a comparative case study of Galați and Brăila Cities is presented. This paper shows how the integration of GIS tools and techniques may improve vulnerability assessments, especially when they are used in conjunction with MCDM methods. ESVI and its integrated maps point out the most vulnerable urban centres and the hotspots of vulnerability within them, allowing for advanced regional and local scale planning of emergency interventions.

Introduction

Vulnerability is a multifaceted, multiscale, dynamic concept that has drawn more and more interest since its emergence in disaster risk reduction research, in the 1970s. Its multidimensionality relates to the diverse nature of the factors and processes that influence vulnerability, being the defining element of the largest sphere in the evolution of vulnerability described by Birkmann (2013).
Although it represents just a component of the overall earthquake vulnerability of urban settlements, systemic vulnerability is of utmost importance when it comes to the reduction of both primary and secondary loss and damage. This dimension of the seismic vulnerability relates to the efficiency of the emergency services that implement crisis management strategies in order to save lives, identify injured people and offer them the necessary medical support, and to reduce the occurrence of potential secondary destructive phenomena (earthquake-induced explosions, fires etc.). Fiedrich (2006) highlights that the first 72 hours that follow the manifestation of a forceful earthquake are crucial for the management of crisis situations. This is the result of the convergence of the short timeframe in which most of the victims are found and rescued (Merciu et al. 2018), of the need to properly accommodate the affected population, and of the potential occurrence of aftershocks. The concept is linked to errors of identifying the optimal routes between areas of high seismic intensity and relief centres (medical units, fire stations) (Ruan et al. 2013; Artese and Achilli 2019), to infrastructure deficiencies and to poorly-elaborated crisis management plans that fail to cover particularly severe situations and local realities.

Systemic vulnerability is one of the least explored dimensions of the seismic vulnerability, and the term is interchangeably used with „capacity” (Armaş 2012). Analyses of this concept may focus on two different elements: i) the accessibility (Armaş 2012; Walker et al. 2014; Rezaie and Panahi 2015; Banica et al. 2017; Alizadeh et al. 2018; Merciu et al. 2018), functionality (Rashed and Weeks 2003), and capacity of emergency services centres (Pitilakis 2011) and ii) the serviceability of transportation networks (Chunguang and Huiying 2000; Bono and Gutiérrez 2011; Bocchini and Frangopol 2012; Argyroudis et al. 2015). However, the practice of combining elements from these two categories is common (Rashed and Weeks 2003; Pitilakis 2011; Tamima and Chouinard 2017; Toma-Danila 2018; Toma-Danila et al. 2020; Albulescu 2021). The latest cited works prove that remote sensing and GIS techniques are frequently employed in this type of assessments, allowing for in-depth perspectives and consistent scientific progress. Like in many other scientific fields, this integration is a real game-changer, whether it provides the tools for the computation of complex vulnerability indicators, or contributes to the validation process.

This vulnerability component emerges from failures of adequate material and human resource allocation in the post-seism period, and of proper financial resource allocation prior to the manifestation of the earthquake. Improvements of these two phases of the resource allocation process require knowledge about the most vulnerable urban centres and the hotspots of vulnerability within them. This calls for up-to-date frameworks that can identify in advance the issues relating to the ability of local emergency services to implement post-seismic interventions, the best paths that these interventions should follow, and to potential earthquake-triggered destructive phenomena (Rezaie and Panahi 2015).

The aim of this paper is two-fold: i) to construct an Earthquake Systemic Vulnerability Index (ESVI) by identifying suitable indicators of this type of vulnerability, and ii) to assess the systemic vulnerability of 6 urban centres in the South-East region of Romania using ESVI. Also, in order to explore particular situations
in the study area and to argument the practical utility of the maps that result in the process of ESVI computation, a comparative case study of Galați and Brăila Cities is presented. The study area was selected due to its high seismic hazard, induced by the proximity of Vrancea Seismogenic Zone (Marmureanu et al. 2004; Radulian et al. 2018). Knowledge about the seismic vulnerability is radical for the development of local scale earthquake mitigation plans. The paper aims to contribute to the construction of systemic vulnerability indexes, by proposing a weighted composite index and by integrating various methods in its validation procedure. The ESVI may serve as a powerful systemic vulnerability assessment tool, adaptable to different contexts and implementable focusing on other areas. Thus, the proposed index is important for both research purposes and practical actions that aim to reduce seismic risks.

The next section describes the study area represented by the South-East region of Romania, focusing on the 6 administrative centres that function as alternatives in the evaluation of the seismic systemic vulnerability. The third section of the paper presents the methodology used in order to compute the index of interest, as well as its validation through Sensitivity Analysis and 2 Multi-Criteria Decision-Making (MCDM) methods. Section 4 covers the presentation of the results, being followed by a comparative case study of 2 urban centres in the study area (Galați and Brăila Cities). The Discussion section encompasses comments on the usefulness of ESVI, also comparing the methodological approach behind ESVI with other systemic vulnerability assessments focusing on individual urban settlements in Romania.

**Study area**

The study area is located in the South-Eastern part of Romania, and it was selected due to its high propensity to seismic hazards. What makes it unique at national level is that it comprises the bending of the Carpathian Arch, the lower sector of the Danube River and the littoral zone of the Black Sea (Figure 1). This richness of landforms and the subsequent variety of landscapes contribute to its economic potential, although the status of the South-East region is one of an underdeveloped area, which also displays different types of spatial disparities (Pirvu et al. 2018).

Moreover, the study area is the most culturally diverse territorial unit, including counties belonging to 3 historical Romanian provinces: Dobruja (Constanța and Tulcea Counties), Moldavia (Galați and Vrancea Counties), and Walachia (Buzău and Brăila Counties). These counties belong to the South-East Development Region of Romania, that covers 15% of the national territory – being the second most extended NUTS 2 unit in this country, and 12.29% of the total population (NIS (National Institute of Statistics) 2021).

The 6 administrative centres of the component counties vary in terms of demographic size, economic profile, polarisation capacity, and their urban sites are also of different nature (Table 1). Half of them are large urban settlements (Constanța, Galați, Brăila Cities), and the other half are medium-size cities. Constanța City presents the highest polarisation potential – functioning as a transnational influence pole, and being followed by the national influence pole of Galați City, by the
Table 1. General information about the administrative centres in the South-East region of Romania

| Administrative centre | County     | Population (NIS (National Institute of Statistics) 2021) | Particularities of the economic profile                                                                 | PGA (UTCB (Universitatea Tehnica de Construcţii Bucureşti) 2013) |
|-----------------------|------------|----------------------------------------------------------|--------------------------------------------------------------------------------------------------------|------------------------------------------------------------------|
| Brăila City           | Brăila     | 196969                                                   | Fluvial transportation, Shipbuilding                                                                   | 0.30 g                                                           |
| Buzău City            | Buzău      | 129085                                                   | Food industry, Wood industry                                                                         | 0.35 g                                                           |
| Constanţa City        | Constanţa  | 308119                                                   | Maritime transportation, Shipbuilding, Petrochemical industry, Tourism                                  | 0.20 g                                                           |
| Focşani City          | Vrancea    | 90446                                                    | Textile industry, Food industry, Wood industry                                                         | 0.40 g                                                           |
| Galaţi City           | Galaţi     | 304985                                                   | Fluvial transportation, Metallurgical industry, Shipbuilding                                          | 0.30 g                                                           |
| Tulcea City           | Tulcea     | 84128                                                    | Fluvial transportation, Metallurgical industry, Shipbuilding, Tourism                                  | 0.25 g                                                           |

Figure 1. Location of the South-East region, Romania.
metropolitan pole of Brăila City and the other 3 regional poles (RDA (Regional Development Agency) 2014). In the study area, maritime and fluvial transportation activities are well-developed: Constanța City and Galați City are the largest seaport, respectively the largest Danubian port in Romania. Each of the 6 administrative centres of the South-East region benefit from a complex economic profile, but there are several particularities that deserve to be mentioned: the cities located along the Danube or on the shore of the Black Sea tie their economic development to opportunities offered by the proximity to these water bodies (Figure 1), while Buzău and Focșani Cities focus on the development of services, food and textile industries.

The South-East region encompasses one of the most active seismogenic zones on the continent (Landes et al. 2004), the Vrancea Seismogenic Zone (Figure 1). This earthquake nest develops at the South-East bend of the Carpathians (Giardini et al., 2013; Radulian 2015), being the only seismogenic area in Romania that displays both a subcrustal and crustal domain (Ismail-Zadeh et al. 2012). The earthquakes that originate here may affect 2/3 of the national territory, as well as the bordering countries (Vacareanu et al. 2013b), and the average rate of occurrence of major earthquakes is estimated at 2-3 events/century (Vacareanu et al. 2013a). Other seismogenic areas in the proximity of or included in the study area are the Predobrogean Depression, the Intramoesian fault and the Shabla-Dulovo Zone (Marmureanu et al. 2004; Radulian et al. 2018)

Therefore, the administrative urban centres in the study area are mainly subject to strong intermediate-depth seismicity, which motivates their selection for the task of assessing their earthquake systemic vulnerability. The high earthquake risk is illustrated by the values of the peak ground acceleration (PGA) in the South-East Region, which vary between 0.20 g (in Constanța City) and the national maximum of 0.40 g (in Focșani City) (UTCB (Universitatea Tehnică de Construcții București) 2013).

There are 3 earthquakes that caused major damages and significant loss of life in Romania in the last few centuries, the most forceful being the „big earthquake” of 1802 (7.9 Mw) (Oncescu et al. 2000). Scarce records of its aftermath are available, but the 7.6-7.7 Mw and the 7.4-7.5 Mw earthquakes of 1940, respectively 1977 (Georgescu and Pomonis 2012; Pantea and Constantin 2013) are better documented. According to Pantea and Constantin (2011, 2013), a large part of the study area was included in the high seismic intensity area of these reference earthquakes.

Local authorities are aware of the vulnerability of the urban building stock, setting the goal of increasing the retrofitting rate (SE ROP (South-East Region Regional Operational Program) 2020). In the aforementioned conditions, the development of optimal emergency intervention strategies and of proper human and material resources allocation should be prioritised, in order to reduce the impact of a major earthquake. Therefore, the current framework serves as a stepping stone in the elaboration of adapted and on point seismic risk mitigation plans.

**Methodology**

In order to estimate the seismic systemic vulnerability of urban settlements, various aspects related to the capacity and efficiency of emergency management services and
| Indicator                                                      | Acronym         | Description                                                                                                                                                                                                 | Type     | Data source                                                                 | References                                                                 |
|---------------------------------------------------------------|-----------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|-----------------------------------------------------------------------------|---------------------------------------------------------------------------|
| Accessibility of emergency services centres                    | SA_HOSPITAL     | The indicator represents the weighted average of different distance intervals to the closest medical unit and of the associated vulnerability classes. It is used to measure the accessibility of medical units in terms of road network-computed distance. | +        | GIS processing                                                             | Armaş (2012), Walker et al. (2014), Rezaie and Panahi (2015), Banica et al. (2017), Tamima and Chouinard (2017), Alizadeh et al. (2018), Toma-Danila (2018), Toma-Danila et al. (2020), Albulescu (2021) |
| Service area of fire stations                                 | SA_FIREST       | The indicator represents the weighted average of different distance intervals to the closest fire station and of the associated vulnerability classes. It is used to measure the accessibility of potential fire sites in relation to fire stations, in terms of road network-computed distance. | +        | GIS processing                                                             | Armaş (2012), Rezaie and Panahi (2015), Banica et al. (2017), Alizadeh et al. (2018), Toma-Danila (2018), Albulescu (2021) |
| Road network                                                  | ROADS           | The aggregate indicator is computed as the weighted average of the road types and the associated vulnerability classes.                                                                                     | +        | OpenStreetMap (2021), Fieldwork                                            | Pitilakis (2011), Rezaie and Panahi (2015), Tamima and Chouinard (2017), Toma-Danila (2018), Toma-Danila et al. (2020) |
| Capacity of locally available medical infrastructure          | NO_DOC          | Shows the availability of highly-qualified medical personnel that can provide assistance to the victims of earthquakes. It excludes the physicians that practice family medicine.                                     | –        | NIS (National Institute of Statistics) (2020a)                              | Albulescu (2021)                                                          |
| Number of hospital beds/1000 people                           | NO_HBEDS        | Indicates the capacity to provide medium or long-time medical care in specialized medical units to the victims of earthquakes.                                                                               | –        | NIS (National Institute of Statistics) (2020a)                              | Albulescu (2021)                                                          |
| Structure of the local medical system                         | MEDICAL_SYS     | The aggregate indicator is computed as the weighted average of the number of medical unit types and of the associated classes that show their contribution to the amelioration of the seismic impact. More complex and better equipped | –        | NIS (National Institute of Statistics) (2020a)                              | Albulescu (2021)                                                          |

(continued)
additional danger sources need to be taken into account. Each of these elements influence systemic vulnerability in a particular way and to a certain extent, acting towards its augmentation or as an attenuating factor. Hence, a proper estimation of systemic vulnerability requires the integration of elements of antithetical weighted roles.

**ESVI indicators**

ESVI represents a weighted composite index that includes both benefit and non-benefit indicators grouped into 3 components that contribute to the emergence of...
earthquake systemic vulnerability: the accessibility of emergency services centres, the capacity of locally available medical infrastructure and secondary danger sources (Tables 2 and 3). The high values of benefit indicators suggest higher systemic vulnerability levels, while the high values of non-benefit indicators lead to the opposite.

The indicators are either single variable derived from the data provided by the National Institute of Statistics (NIS), or composite indicators that integrate results of GIS processing and the weighted averages of specific components and associated elements. For the composite indicators like SA_HOSPITAL, SA_FIREST, ROADS and INDUSTRY, the specific components were attributed vulnerability classes as described in Table 4, while for the non-benefit indicator called MEDICAL_SYS, the integrated types of medical units were attributed classes that express the contribution to the attenuation of systemic vulnerability.

GIS processing

The service areas of the emergency services centres are computed using the Network Analyst tool of ArcMap 10.2. Beginning with the identification of the relief centres and the extraction of the road network via OpenStreetMap Toolbox, the GIS-based methodology aims to determine which urban neighbourhoods are located at different distances from the medical units and fire stations (Figure 2). It should be highlighted that out of the total number of hospitals in an urban settlement, only those that have the adequate capacity and profile are included in the analysis. In the case of South-East region, psychiatric hospitals and maternity hospitals are left out of the analysis, as it can be argued that the medical care they provide should focus on their particularly vulnerable patients, even in a powerful earthquake scenario.

There are multiple medical units and fire stations whose service areas need to be computed, which leads to their overlapping. This issue is addressed by polygons processing (Figure 2), which involves the creation of a single polygon which includes all the service areas of a certain interval and the elimination of the overlapping parts, using the Overlay and Erase tools of Analyst Tools.

ESVI computation

The weighing of the indicators and of their categories is performed using the Analytic Hierarchy Process (AHP) and the final weights are obtained by multiplying these results. To fit the AHP framework, the categories of accessibility, medical infrastructure and secondary danger related indicators are considered evaluation criteria, while the indicators function as evaluation sub-criteria.
Because each criterion includes a number of constitutive elements no larger than 3, the AHP scale of absolute numbers used to express the results of the pairwise comparisons calculated at the criteria and sub-criteria levels is simplified as follows: 1 – the compared elements are of equal importance, 1.5 – one element is slightly more important than the other, 2 – one element is definitely more important than the other.

Finally, the ESVI integrates the normalized values of the indicators and their weights (Figure 3):
$$ESVI = \sum_{i=1}^{n} Bi \cdot W_{Bi} - \sum_{j=1}^{m} NBj \cdot W_{NBj}$$

Where: $B = \text{benefit indicators vector}, \ NB = \text{non-benefit indicators vector}, \ W = \text{final weights vector}, \ n = \text{number of benefit indicators}, \ m = \text{number of non-benefit indicators}$

**ESVI validation**

The validation procedure of ESVI is based on i) Sensitivity Analysis and ii) Multi-Criteria Decision-Making methods, that are more and more applied in order to assess seismic vulnerability (Rashed and Weeks 2003; Armaş 2012; Walker et al. 2014; Banica et al. 2017; Albulescu et al., 2019; Albulescu 2021).

An intrinsic debatable aspect of the AHP is the degree of subjectivity in the expert judgments that coordinate the weighing process (Chen et al. 2013). Sensitivity Analysis (SA) constitutes a useful investigation tool of the way the indicators’ weights influence the results, also testing the robustness of the ESVI in the aforementioned conditions of uncertainty. The one-at-a-time (OAT) approach of the SA implies that the weights of the indicators should be changed with each other, one at a time. By this, the weight of the first indicator is interchanged with the weight of the second indicator – while the other weights are invariable, of the third etc. In the case of ESVI, the exchange of weights should be done only at category level, meaning that there are 3 possible exchanges for each of the 3 criteria: the weights of the first and second sub-criteria in that particular category, the weights of the first and the third sub-criteria, and the weights of the second and the third sub-criteria.

Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and Weighted Product Model (WPM) are applied in order to rank the alternatives represented by the 6 urban centres in the study area (Table 5), taking into consideration the criteria and sub-criteria integrated by ESVI, together with their AHP-computed weights. The capacity to integrate indicators that are expressed using different
measurement units and that act as benefit or non-benefit elements, as well as a large number of evaluated alternatives, make them suitable for this task.

The results provided by MCDM methods are usually heterogeneous in nature, motivating the use of more than one method for the validation procedure. The issue of divergent results is addressed by Aggregate Methods (Colson and De Bruyn 1989), namely Borda, Copeland and Average of Ranks. The rankings obtained via ESVI, TOPSIS and WPM are analysed using the 3 Aggregate Methods, leading to a new set of rankings (Figure 4). The final ranking is computed as the average of the rankings that result from Borda, Copeland and Average of Ranks methods.

In order to establish which set of initial results is the most accurate, the ESVI, TOPSIS and WPM results are compared with the final ranking via Residual Sum of Squares (RSS) method. The lowest RSS value is associated to the smallest alterity from the final ranking, meaning that it belongs to the method with the highest accuracy. This statistical technique is usually used in regression analysis in order to determine the dispersion of data points, but it also serves the purpose of identifying the data that best fits the selected standard.

### Table 5. Short description of AHP, TOPSIS and WPM methods.

| MCDM method | Description | References |
|-------------|-------------|------------|
| AHP         | The method allows for a hierarchically-structured segmentation of the problem at hand. The first level corresponds to the goal of the problem, being followed by the evaluation criteria and sub-criteria. The last level includes the evaluated alternatives. The elements on each level are independent to each other and are compared using the pairwise comparison technique and a predefined scale of absolute numbers. | Saaty (1977, 2004) |
| TOPSIS      | TOPSIS may be used to evaluate and rank the alternatives, relaying to the identification of a compromise solution, located at minimum distance to the positive ideal solution and maximum distance to the negative ideal solution. It may integrate benefit and non-benefit criteria and sub-criteria. | Hwang and Yoon (1981), Hwang et al. (1993) |
| WPM         | The method may be used to perform dimensionless analysis, as it erases any measurement units used to express the performance of the alternatives in regard to each criterion. It is a derivation of the Weighted Sum Model (WSM), which uses the multiplication operation to rank the alternatives, integrating the weights of the considered criteria. | Triantaphyllou et al. (1998), Triantaphyllou (2000) |
Results

The weighing of the indicators and of the categories they belong to is done according to expert judgments grounded in scientific literature, that also take into account local scale particularities. The validity of the judgments that operate at each category level is proved by specific Consistency Ratios, which are lower than the threshold of 0.1 set by Saaty (2004).

The highest weight is attributed to the criteria referring to the accessibility of emergency services (0.4538), as the decision-makers consider that the service areas of the medical units and fire stations, as well as their accessibility, are decisive in the post-seism period. This is supported by Amram et al. (2011), who state that the distance from trauma management centres is negatively correlated with the survival of the victims. At this level, the most important indicator is represented by the vulnerability of road types of being blocked by collapsed buildings in a powerful earthquake scenario (0.4257), which is based on the findings that accessibility reduction may amplify a crisis situation (Yi and Kumar 2007). The road network conditions the accessibility towards medical units (0.3255), which are considered more important than fire stations (0.2487) in the aforementioned situation, because past events show that the probability of earthquake-caused injuries is higher than the probability of earthquake-caused forceful fires (Douglas 2007; Lee et al. 2008).

Table 6 shows that the criterion of medical infrastructure is the second one in terms of relevance (0.3470), for the reason that it integrates sub-criteria related to the human and material resources which contribute to the attenuation of an earthquake-triggered crisis situation (McLafferty 2003). The human resources fulfil the most important role in treatment of victims in the post-seism period, which often require immediate medical intervention and prolonged medical supervision. Assuming that a high-magnitude earthquake may extend its impact at regional scale, the local medical staff have to provide the better part of the consistent medical support, as the input of medical personnel from other nearby urban centres is rather unreliable in major crisis
situations. On the other hand, the capacity of the local medical infrastructure may be augmented by constructing campaign hospitals and temporary shelters, leading to lower weights of the specific indicators.

Secondary danger indicators are considered the least important (0.1991) in the current geographic setting, as the probability of landslide-triggered by earthquakes is low, except for the Subcharpatian area (Grozavu and Patriche 2021) and the tsunami hazard on the Western coast of the Black Sea is currently appreciated to be of low to moderate level (Oaie et al. 2006; Papadopoulos et al. 2011; Zaytsev et al. 2015). Decision-makers argue that the probability of earthquake-induced fires and/or explosions in industrial areas is the most important indicator in this category (0.4258). This kind of fires would have larger proportions than the ones that may be caused by inflammable substances leaked after the damaging of fuel stations or gas pipelines; rationale that explains the weights of the indicators in the secondary danger category (Table 6).

The calibrated weights hierarchy is dominated by indicators referring to the accessibility of emergency services (1. ROADS, 3. SA_HOSPITAL, 4. SA_FIREST) and to the medical infrastructure available at local scale (2. NO_DOCS, 5. MEDICAL_SYS, 6. NO_HBEDS) (Figure 5). Due to the low relative weight of the category (0.1991), the indicators concerning secondary danger sources occupy the last 3 places, in the order of importance established at category level. The hierarchy suggests a balanced distribution of the relative importance values attributed to the 9 indicators of seismic systemic vulnerability, which may be traced to the implementation of the simplified AHP scale of absolute numbers.

According to ESVI, Brăila City is characterised by the highest earthquake systemic vulnerability in the South-East region of Romania, while the lowest level of this vulnerability type belongs to Tulcea City. Buzău and Constanța Cities present high

Table 6. Matrices of pair-wise comparisons of the indicators weighed via AHP.

| Categories of indicators     | 1   | 2   | 3   | Weights | Final weights |
|------------------------------|-----|-----|-----|---------|--------------|
| (1) ACCESSIBILITY            | 1   | 1.5 | 2   | 0.4538  |              |
| (2) MEDICAL_INFR             | 1/1.5 | 1   | 2   | 0.3470  |              |
| (3) SEC_DANGER               | 1/2 | 0.5 | 1   | 0.1991  |              |
| Consistency ratio: 0.0173    |     |     |     |         |              |
| Accessibility of emergency services |     |     |     |         |              |
| (1) SA_HOSPITAL              | 1   | 1.5 | 1/1.5 | 0.3255 | 0.1477       |
| (2) SA_FIREST                | 1/1.5 | 1   | 1/1.5 | 0.2487 | 0.1129       |
| (3) ROADS                    | 1.5 | 1.5 | 1   | 0.4257  | 0.1932       |
| Consistency ratio: 0.0165    |     |     |     |         |              |
| Medical infrastructure       |     |     |     |         |              |
| (1) NO_DOCS                  | 1   | 2   | 1.5  | 0.4633  | 0.1607       |
| (2) NO_HBEDS                 | 1/2 | 1   | 1   | 0.2554  | 0.0886       |
| (3) MEDICAL_SYS              | 1/1.5 | 1   | 1   | 0.2811  | 0.0975       |
| Consistency ratio: 0.0085    |     |     |     |         |              |
| Secondary danger             |     |     |     |         |              |
| (1) FUELST_D                 | 1   | 1/1.5 | 1.5  | 0.3255  | 0.0648       |
| (2) INDUSTRY                 | 1.5 | 1   | 1.5  | 0.4257  | 0.0847       |
| (3) GAS_PIPES                | 1/1.5 | 1/1.5 | 1   | 0.2487  | 0.0495       |
| Consistency ratio: 0.0165    |     |     |     |         |              |
systemic vulnerability levels, and the median place is occupied by Galați City (Table 7). Although Focșani City is located at the lowest distance from the Vrancea Seismogenic Zone, its systemic vulnerability is low.

SA shows that the outputs of the weights’ exchange fit the initial ESVI ranking in 7 out of 9 cases. Therefore, the 77.77% Consistency Ratio validates the ESVI results. Modifications in the cities’ hierarchy emerge when the weight of the NO_DOCS and the NO_HBEDS/MEDICAL_SYS indicators are interchanged: the extreme levels of systemic vulnerability still correspond to Brăila and Tulcea Cities, but the upper and lower parts of the median ranking section is modified in the case of the NO_DOCS-NO_HBEDS exchange, respectively of the NO_DOCS-MEDICAL_SYS exchange.

Comparing the rankings resulting from the implementation of MCDM methods with the ESVI ranking, both convergence and divergence points may be identified (Table 7):

- Both ESVI and TOPSIS rankings set Brăila and Buzău Cities on the first places in terms of systemic vulnerability, while the WPM indicates that Constanța City presents the highest earthquake systemic vulnerability.
- Buzău and Galați Cities occupy the same places (2, respectively 4) in all the 3 hierarchies.
- The positions of Focșani and Constanța Cities significantly differ from one ranking to the other.

In order to compute a standard ranking that may serve as reference, the ESVI, TOPSIS and WPM hierarchies are integrated in Borda, Copeland and the Average of ranks methods. The average of the new rankings (Borda, Copeland and Average of ranks hierarchies) represents the final ranking, and the dissimilitude of the ESVI and MCDM methods rankings is used as a proxy for the accuracy of the results (Table 8). The RSS method is used to compute the divergence from the standard, showing that the lowest RSS value suggests the best fit of the standard. In this case, the ESVI ranking is identical to the final one, leading to a null RSS value (Table 8). This means that the hierarchy obtained via ESVI is the most accurate one.
Comparative case study of Galați and Brăila cities

Although they are not located at the ends of the ESVI spectrum, Galați and Brăila Cities were selected for this comparative case study because of their shared physical geographic features, their development differences and their historically rooted rivalry. Both of the urban settlements are ports on the Danube River, Galați City being the larger one in terms of capacity and population. Brăila City is located in the Brăila Plain (part of the larger Romanian Plain), on the fluvial terraces on the Western shore of the Danube, and Galați City lies in the Covurlui Plain (part of the Moldavian Plateau), extending over the fluvial terraces of the Danube and Siret Rivers (Figure 6).

Under the communist regime, Galați City developed rapidly, acquiring the status of the largest siderurgy centre in Romania, but Brăila City went through a slower paced and lower-level industrialisation process. The disparity of urban growth, both in terms of population and territorial expansion, may be traced to this differential industrial growth, as well as to the development of the two port areas since the Adrianople Treaty (1829). Since 1989, the industrial performance of both cities has declined; their economic development focusing on river transportation, the shipbuilding industry, and complex tertiary activities.

Only 21 km apart, the two urban settlements belonged to different countries – Galați City to Moldavia and Brăila City to Walachia, up until the middle of the 17th century. This explains why they have grown into well-known competitors, disputing cargos, hinterlands, economic investments and the location sites for technological advancements in the Lower Danube Basin. Changing the historical course of competitive evolution, modern times show that the economic development processes of Galați and Brăila Cities are tied (Săgeată 2004, 2007), as some suggest by the new 2-km long bridge over the Danube (Beciu and Arghiroiu 2019). However, at the end of the last century, Ungureanu (1980) signalled the perspective of a bipolar conurbation and of the parallel development of the two cities. This urban system would represent a novelty in the settlement network of Romania, integrating two first rank cities that were for centuries the nuclei of two distinctive territorial systems (Țurcănașu, 2005).

Both Galați and Brăila Cities are located in the epicentral areas of the major Vrancea earthquakes that caused significant loss and damage in Romania in the last century, namely the 7.6-7.7 M_W earthquake of 1940, and the 7.4-7.5 M_W earthquake of 1977. In their analysis of building damage and territorial casualty patters of the two seismic events, Georgescu and Pomonis (2012) estimate that the earthquake of

| Cities | ESVI Value | TOPSIS Value | WPM Value | Borda Ranking | Copeland Ranking | Average of ranks | Ranking |
|--------|------------|--------------|-----------|---------------|-----------------|-----------------|---------|
| Brăila | 0.0706     | 0.7374       |           | 1             | 1               | 1               | 1       |
| Buzău  | 0.0576     | 0.6515       |           | 2             | 2               | 2               | 2       |
| Constanța | 0.0506   | 0.4131       |           | 3             | 3               | 3               | 3       |
| Focșani | 0.0429     | 0.3635       |           | 5             | 5               | 5               | 5       |
| Galați | 0.0477     | 0.5582       |           | 6             | 5               | 4               | 4       |
| Tulcea | 0.0363     | 0.4459       |           | 6             | 6               | 6               | 6       |
1940 caused the death of 34 people and the injury of 40-130 people in Galați City. In 1977, the 7.4-7.5 MW earthquake caused the death of 3 people and the injury of 5 people in Brăila County. The same authors estimate that over 5% of the dwellings in Galați county were destroyed by the 1977 earthquake; the percentage was around 4% for Brăila County. However, the percentage of the dwellings that required repairing after the seismic event is higher in the case of Brăila County (17% of the total dwelling stock of the county) than of the neighbouring city (6%). More buildings were affected in Brăila County than in Galați County: 33.9% of the total dwelling stock of the county (4th place at national level), respectively 8% of it (11th place at national level) (Georgescu and Pomonis 2008).

ESVI shows that Brăila City presents a higher level of systemic vulnerability than Galați City, which is confirmed by the results of the MCDM methods. Additionally, the rankings obtained via Aggregate Methods support the ESVI hierarchy, where Brăila City registers the highest value in the South-East region, and Galați City occupied the 4th place (Table 8). In order to properly understand why the larger Danubian settlement is less vulnerable from the systemic point of view, a comparative analysis of the considered components is required.

| Cities      | Final Ranking | ESVI Ranking | ESVI RSS | TOPSIS Ranking | TOPSIS RSS | WPM Ranking | WPM RSS |
|-------------|---------------|--------------|----------|----------------|------------|-------------|---------|
| Brăila      | 1             | 1            | 0        | 1              | 0          | 3           | 4       |
| Buzău       | 2             | 2            | 0        | 2              | 0          | 2           | 0       |
| Constanța   | 3             | 3            | 0        | 6              | 9          | 1           | 4       |
| Focșani     | 5             | 5            | 0        | 3              | 4          | 6           | 1       |
| Galați      | 4             | 4            | 0        | 4              | 0          | 4           | 0       |
| Tulcea      | 6             | 6            | 0        | 5              | 1          | 5           | 1       |

Table 8. The RSS values and rankings obtained via ESVI, TOPSIS and WPM methods.

Figure 6. Location of Galați and Brăila Cities and their component neighbourhoods, Romania.
Accessibility of emergency services centres

In terms of accessibility towards emergency services centres, Brăila City registers higher scores of all the benefit indicators – which correspond to higher levels of systemic vulnerability, although the difference between the two Danubian urban centres in terms of road network vulnerability is insignificant. This dominance majorly contributes to ESVI values, because the weight of the accessibility criteria is the largest, and the weights of the component sub-criteria are also of high value (Figure 5).

Specific service area values of medical units (Table 9) show that while most of Galaţi City territory (70.65%) lies within 2000 m to the closest medical unit, only a little more than a third (38.81%) of Brăila City territory is comprised within this limit. Also, the percentage of urban territory located at more than 3000 m to the proximal medical unit rises to 40.79% in case of Brăila City and to 14.94% in case of Galaţi City. These differences are explained by the higher number of hospitals in Galaţi City – 6 hospitals and one ambulance centre are included in this analysis, compared to the 3 hospitals and one ambulance centre located in Brăila City, and also by the spatial distribution of these trauma centres and the configuration of the urban street network (Figure 7).

In the largest Danubian port settlement of Romania, a cluster of 4 medical units extends its proximal service area of 0-1000 m in the Northern part of the territory, and the densely populated neighbourhoods in the South-West, that emerged as a result of the industrial boom of the 1960-1970 (Micro 17, Micro 19, Țiglina 3 neighbourhoods) are also in proximity of 2 medical units, of which one represents the largest hospital in the Southern part of the Moldavia Region. The General Railways hospital is located in the South-Eastern part of the city, providing medical services for the inhabitants of the Southern old residential area, which are known to be subject to poverty and other connected social issues. Thus, only sparsely populated (the Northern part of Bariera Traian neighbourhood) or industrial peripheral urban areas (Damen Shipyard area) are located to more than 3000 m to the closest medical unit.

The distribution of service areas of medical units in Brăila City is very different, as the emergency services centres of interest are located along a line that starts from the centre of the semi-circular-shaped urban territory and extends to the South-West. This means that the neighbourhoods in the central and Southwestern part of the city (the Civic Center, Tineretului, Școlilor, Hipodrom, Viziru II, Călărași 4, Ansamblul Buzăului, Lacu Dulce, Dorobanți, Gării neighbourhoods) are characterised by a high level of accessibility to medical units, while the Northern and Northwestern areas

---

Table 9. Service areas of the emergency services centres in Galaţi and Brăila Cities.

| Distance (m) | Medical units | Fire stations |
|-------------|---------------|---------------|
|             | Galaţi City | Brăila City | Galaţi City | Brăila City |
| 0-1000      | 7.98         | 3.39         | 5.00        | 1.54        |
| 1000.01-2000| 13.46        | 7.04         | 11.90       | 5.32        |
| 2000.01-3000| 4.37          | 5.48         | 5.40        | 7.98        |
| 3000.01-4000| 0.64          | 5.35         | 2.20        | 5.62        |
| over 4000   | 3.89          | 5.61         | 5.83        | 6.41        |
(Minerva, Catanga, Progresu, Brăilă, Pisc, Locuri Noi neighbourhoods) are disadvantaged from this point of view.

Similar inequalities are noticeable when it comes to the distribution of the service areas of fire stations: the distance interval that occupies the largest part of Galați City territory (39.23%) is 1000.01-2000 m, but in the case of Brăila City, 29.70% of the territory is located at 2000.01-3000 m to the closest fire station (Table 9). Galați City is protected from fire destruction by 4 detachments of firefighters, which explains why 55.72% of its territory is located within the limit of 2000 m to the proximal facility of this type. On the contrary, there is only one firefighter detachment in the neighbouring city, leading to a percentage of 25.54% that fits this limit.

In short, almost a half of Brăila City territory (44.75%) is located at more than 3000 m from the only fire station. This facility has a central position, including in its 2000 m service area the neighbourhoods called Gării, Apollo, Dorobanți, Școlilor, Tineretului, Comorovca, Islaz and M. Kogălniceanu. The extension of this proximal distance interval is blocked to the East by the presence of the railway, which separates M. Kogălniceanu, Apollo, 1 Mai and Dorobanți areas from Catanga, Chernea and Lacu Dulce areas, acting as an enabler of systemic vulnerability. Figure 8 illustrates that the service areas of the fire station extend in a concentric manner, so the peripheral neighbourhoods of Locuri Noi, Vidin, Pisc, Minerva, and especially Ansamblul Buzăului, Radu Negru and Brăila Sud areas are less accessible for firefighters interventions.

The fire stations in Galați City occupy central, Eastern and Southwestern positions, and their lowest vulnerability distance interval (0-1000 m) lies on the territory of the
old residential area, Center, Piața-Traian, Micro 14, I.C. Frimu, and Micro 19 neighbourhoods. Also, the other densely populated areas of different ages, located on one side and the other of G. Coșbuc Boulevard are within the 2000 m limit to the closest fire stations (Figure 8). Only the Easternmost and the Northernmost urban areas have a low level of accessibility for firefighters interventions.

The cities differ in regard to the street network configuration. Galați City presents a combined street pattern, formed by an alternation of various grid and irregular patterns. The street configuration of Brăila City is of semi-circular type, with 4 connective half-rings and 7 radial high traffic routes (Figure 9). The Danube River conditions the development of these street configurations, as the former city extends on the outside of its South-West-North-East bend, between the Brateș Lake and Cătușa Lake, and the latter has developed to the West of this important waterway. The Northern and Southern areas of Brăila City display a grid pattern, imposed by specific urban planning trends.

The arterial roads which would be of primal importance in a 7MW (or more) earthquake are G. Coșbuc, Basarabiei, Siderurgiștilor, Brăilei, Marea Unire, Calea Prutului Streets in Galați City, and Calea Călărașilor, Calea Galați, Baldovinești, Al. I. Cuza, Independenței, Dorobanților, 1 decembrie 1918, M. Mălaeru Streets in Brăila City. All of them are primary or secondary streets that ensure the day-to-day transit and also the access of emergency service teams to vulnerable urban areas.

The values of the indicator that expresses the road network vulnerability are comparable (3.75 for Galați City and 3.77 for Brăila City). Low vulnerability streets, like primary streets and trunk roads represent 12.2% of the total length of the road.
network in Galați City and 11.96% of it in the case of Brăila City. Residential streets, which present a high vulnerability level, dominate the network of both urban settlements, but the percentages differ: 31.59% for Galați City and 57.75% for Brăila City (Table 10). On the other hand, the most vulnerable types of streets (living streets, service streets and unclassified streets) account for more than a third (37.72%) of the road network in Galați City, and for almost a quarter (23.49%) of the road network in Brăila City. Thus, the percentages of highly vulnerable and very highly vulnerable streets in the two cities balance each other, leading to a small difference value of the overall road vulnerability indicator.

**Medical infrastructure capacity**

Galați City is better equipped in terms of medical infrastructure than Brăila City; which may be argued by bringing attention to the human medical resource and the structure of the local medical system. Functioning as a medical regional centre, Galați City presents a more diverse medical system of large capacity, comprising 8 hospitals, one specialised medical centre equipped with hospital beds, one health centre and one polyclinic. On the other hand, there are only 3 hospitals in Brăila City and no public secondary-level medical units (NIS 2020a). The discrepancies regarding medical infrastructure capacity are explained by the differences of demographic size between the two urban centres (Table 1) and of spatial extension. These factors account for the differences regarding the number of doctors/1000 inhabitants and the number of hospital beds/1000 inhabitants (Table 3).
In a major earthquake scenario, the presented inequalities indicate that Galați City is theoretically better prepared to provide the medical care much needed in the post-seism period, but to a larger contingent of people that may be injured by collapsing buildings or secondary destructive phenomena. In the case of the neighbouring city, the amelioration of the seismic impact may require augmentation of the medical infrastructure by constructing campaign hospitals. Also, a low number of hospitals is associated to difficulties in maintaining routine healthcare services, in the context of additional patients inputs determined by a powerful earthquake.

Thus, it is more probable that Galați City would prove its ability to self-support from the medical point of view in the aftermath of an earthquake-induced crisis situation, while Brăila City may require external assistance. Such implications of the results have to take into consideration the probability of injuries in the two urban centres, which are both characterised by loess geologic settings and old building stocks that need urgent retrofitting (Albulescu 2021); geotechnical and physical vulnerability factors which are more potent in case of Brăila City (Georgescu and Pomonis 2008).

### Secondary danger

In the matter of secondary danger sources, Brăila City scores higher concerning the density of fuel stations, while Galați City presents a more developed industrial infrastructure that may be connected to a higher vulnerability to earthquake-triggered destructive phenomena (Table 3). The industrial units in the two Danubian cities belong to similar industries, but their development level significantly differs. Galați City is the site of the largest siderurgy unit in Romania, also possessing highly advanced shipbuilding and food industrial units, together with medium or low-level units in the energy, mechanical, building materials, wood and textile industries. The shipbuilding and textile industries in Brăila City are moderately developed; the other presented industrial branches being represented by low-level units.

The potential of fires and/or explosions caused by damages of gas pipelines is higher in Galați City – whose gas duct network is more extended. What is more, the potential secondary destructive phenomena related to fuel stations damages, expressed by the density of petrol stations, is similar in the two cities, because the number of fuel stations (23 in Brăila City and 25 in Galați City), as well as the inhabited area (26.89 km² in Brăila City and 30.35 km² in Galați City) are comparable. Figure 9
shows that in both urban centres, fuel stations are located along the most transited streets – G. Coșbuc Boulevard and the Ring Road in Galați City, and Baldovinești, Dorobanților, Calea Galați Streets in Brăila City. One common problem is that the primary streets that section the cities in two parts (G. Coșbuc and Dorobanților Boulevards) are flanked by numerous fuel stations which may be damaged during a major earthquake; potential fires and/or explosions threatening the densely populated nearby areas.

*The particularly vulnerable Dimitrie Cantemir neighbourhood*

One urban area that stands out in terms of earthquake systemic vulnerability is Dimitrie Cantemir neighbourhood. The 10-square km peripheral residential area extends on Brăila County’s territory, on the left bank of the Danube and on the right bank of the Siret River (Figure 10); but belongs to Galați City from the administrative point of view. The estate was developed in 2003-2012, and it was meant to include local medical and education facilities. Currently, it comprises more than 340 dwellings that are state-owned and rented at low prices to the young population.

There are major problems concerning the provision of electricity, natural gas and sanitation services, mainly due to the 1 km distance to Galați City. The same remoteness issue, augmented by the presence of a railway and a bridge over the Siret River that have to be crossed in order to reach the neighbourhood is also the source of a high-level systemic vulnerability. The closest medical unit is located at more than 4 km, and the proximal fire station at more than 5 km. This low accessibility of the area to emergency intervention teams, in conjunction with the problematic availability of basic lifelines, make Dimitrie Cantemir neighbourhood particularly vulnerable in a major earthquake scenario.
Discussion

The necessity of elaborating earthquake systemic assessments that focus on urban centres in Romania is pointed out by the high seismic risk associated with the nearby seismogenic areas, but also by the low number of scientific works that study earthquake vulnerability (Armaș 2012; Armaș et al. 2016, 2017; Banica et al. 2017; Albulescu 2021), alongside the scarcity of research concerning solely the systemic vulnerability (Toma-Danila 2018; Toma-Danila et al. 2020). Moreover, the South-Eastern region has never been studied in terms of seismic vulnerability prior to this; Galați and Focșani Cities being the only settlements in this country that were previously included in a comparative multi-criteria seismic vulnerability assessment (Albulescu 2021).

Comparing ESVI with the approach presented by Toma-Danila (2018), notable differences are observed: while ESVI uses an indicator-based framework in order to comparatively assess the earthquake systemic vulnerability of multiple urban settlements, the GIS-based framework developed by Toma-Danila (2018) and Toma-Danila et al. (2020) addresses the problem by using Monte Carlo simulations that generate potentially disrupted network configurations in Bucharest, and analyse their impact on traffic and on the efficiency of post-seism emergency interventions. On the other hand, ESVI includes only general data on possible earthquake-triggered road service-ability failures, compensating this by a broader range of accessibility, medical infra-structure and secondary danger indicators. Both of the GIS-based frameworks may be replicated and applied to other urban settlements, in the endeavour to acquire up-to-date information on the specific systemic vulnerability.

It should not be forgotten that the paper focuses on the assessment of only one dimension of seismic vulnerability and that a comprehensive evaluation of this notion also includes aspects relating to the geotechnical, physical, social and economic vulnerability (Armaș 2012; Armaș et al. 2016, 2017; Banica et al. 2017; Alizadeh et al. 2018; Albulescu 2021). In this context, it is possible that the overall seismic vulnerability of Braiła City to be lower than the one of the other urban centres. Thus, the results should be interpreted relating solely to the systemic side of seismic vulnerability.

Another limitation of the paper refers to the failure to integrate indicators commonly used in systemic vulnerability assessments. One example is the density of the buildings, for which adequate and up-to-date data are not available in Romania (Armaș 2012; Armaș et al. 2016, 2017; Banica et al. 2017; Alizadeh et al. 2018; Merciu et al. 2018). The Statistics Departments that operate at county level may provide data concerning only the residential buildings, originating to the last census of population and dwellings, which took place in 2011. The datasets are not accompanied by spatial references and may be used only for coarse analyses. The issue may be addressed by combining remote sensing and machine learning algorithms that can extract building objects. In order to avoid the distortion of the results by including obsolete data, we preferred to develop a methodological framework that focuses on the described components (Table 2).

A third limitation relates to the premise of functional relief centres, whose electricity and water supply networks remain intact or are only slightly damaged after a
high-magnitude earthquake. Considering the old age of the hospital buildings and of certain segments of the water distribution network in the study area, this premise may easily be placed under a question mark.

Taking into consideration the novelty of the practical information presented in the Results section, together with the fact that the evaluated urban centres lie in proximity of the Vrancea Seismogenic Zone, this study suits the purpose of elaborating better local scale emergency intervention plans. Given the fact that the evaluated cities belong to the South-East Development Region, the efforts that aim to reduce systemic vulnerability may be coordinated at regional scale, also integrating local scale particularities that may function as complementary elements. In addition, the paper contributes to the advancement of systemic vulnerability index construction by proposing a valid methodological framework and a list of adequate indicators, part of which are GIS-derived. The resulting maps may be used to depict the systemic vulnerability hotspots of the evaluated urban areas, as well as to compute the most efficient routes between these areas and relief centres. This is of particular importance, especially since the Red Intervention Plans that operate in the selected counties do not comprise such information, and are developed following a standardised approach that overlooks local scale aspects.

Conclusions

Knowing in advance which are the areas that will most probably require intervention after a major earthquake, identifying the paths that the intervention should follow for optimal results, and evaluating the ability of local emergency services to implement such intervention are stepping stones towards constructing sound risk reduction plans. This paper aims to contribute to the elaboration of such strategies by evaluating the systemic vulnerability of the administrative centres located in an area with a very high propensity for earthquakes.

The ranking obtained using the proposed framework is validated by the Borda, Copeland and Average of Ranks methods, as well as by the Sensitivity Analysis. According to ESVI, the hierarchy of the major urban settlements in the South-East region of Romania in terms of systemic vulnerability (1. Brăila City, 2. Buzău City, 3. Constanța City, 4. Galați City, 5. Focșani City, 6. Tulcea City) is independent of the demographic size and the economic profile of the alternatives.

The comparative case study of Galați and Brăila Cities indicates that the former Danubian city presents a higher accessibility level to the emergency services centres, which are also more numerous and better equipped. On the contrary, the medical infrastructure available in Brăila City is fitted to provide the designed services in normal state situations, but this urban settlement may find itself in need to call for external medical support in case of a major earthquake. When it comes to potential secondary dangers, the better developed industrial infrastructure of Galați City may prove to correspond to a higher propensity for large fires and/or explosions, while its more extended gas pipeline network may be the source of leakages that spark smaller earthquake-triggered fires. The two urban settlements are similar in terms of road network vulnerability and fuel stations density. The comparative case study brings to
attention that the most vulnerable neighbourhoods in terms of overall systemic vulnerability are the peripheral ones: Bariera Traian and the industrial area of Damen in Galați City, and Locuri Noi, Vidin, Pisc, Minerva and the Northern industrial area in Brăila City.

Systemic vulnerability accounts only for a part of the overall earthquake vulnerability of a certain space. Nonetheless, its modelling is crucial for the amelioration of the impact of a $7\,M_W$ (or larger) earthquake, due to the narrow timeframe in which most of the successful emergency interventions take place. In order to obtain optimal impact amelioration, this timeframe has to be dedicated to the implementation of specific predefined and locally-adapted rescue actions, that are not a result of on-the-spot decisions made by local authorities or emergency services teams which are pressured by time and other factors. Thus, both preventive and mitigation plans have to be developed and constantly improved, with the help of prior systemic vulnerability assessments and of GIS techniques.

When considering the various seismic vulnerability sources specific to the South-East region – among which the proximity to the Vrancea Seismogenic Zone, the loess geological setting of some included counties, the old and under-retrofitted building stock of most of the urban centres, and the general character of the emergency intervention plans that ought to be implemented in a major earthquake scenario, the importance of systemic vulnerability level increases, as its reduction is preferable in terms of financial costs and time. This modelling of systemic vulnerability also sets optimistic perspectives regarding the possibility to prevent disastrous loss and damage.

Disclosure statement
No potential conflict of interest was reported by the authors.

Funding
This research was funded by the Department of Geography in the Faculty of Geography and Geology, Alexandru Ioan Cuza University of Iași.

Data availability statement
The data that support the findings of this paper are available and may be requested from the corresponding author (Albulescu A.C.).

References
Albulescu A-C, Grozavu A, Larion D. 2019. A Gis-Based Application Of Fuzzy Ahp and Classical Topsis Methods On Assessing The Seismic Vulnerability of Galați City, Romania. International Multidisciplinary Scientific Geocconference : SGEM. 19(2.1):737–744.
Alizadeh M, Ngah I, Hashim M, Pradhan B, Pour AB. 2018. A hybrid analytic network process and artificial neural network (ANP-ANN) model for urban earthquake vulnerability assessment. Remote Sensing. 10(6):975.
Amram O, Schuurman N, Hameed SM. 2011. Mass casualty modelling: a spatial tool to support triage decision making. Int J Health Geogr. 10(1):40–47.

Argyroudis S, Selva J, Gehl P, Pitilakis K. 2015. Systemic seismic risk assessment of road networks considering interactions with the built environment. Comput-Aided Civ Infrastruct Eng. 30(7):524–540.

Armaş I. 2012. Multi-criteria vulnerability analysis to earthquake hazard of Bucharest, Romania. Nat Hazards. 63(2):1129–1156.

Armaş I, Ionescu R, Gavrîş A, Toma-Danila D. 2016. Identifying seismic vulnerability hotspots in Bucharest. Appl Geogr. 77:49–63.

Armaş I, Toma-Danila D, Ionescu R, Gavrîş A. 2017. Vulnerability to earthquake hazard: Bucharest case study. Romania. Int J Disaster Risk Sci. 8(2):182–195.

Artese S, Achilli V. 2019. A GIS tool for the management of seismic emergencies in historical centers: how to choose the optimal routes for civil protection interventions. In: International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences, GEORES 2019 – 2nd International Conference of Geomatics and Restoration, Milan, Italy.

Banica A, Rosu L, Muntele I, Grozavu A. 2017. Towards urban resilience: A multi-criteria analysis of seismic vulnerability in Iasi City (Romania). Sustainability. 9(2):270.

Beciu S, Arghirou AG. 2019. Will the new bridge over Danube create a tourism sustainable hub in the urban area of Brăila-Galăți-Măcin? In: Conference Proceedings: New Trends in Sustainable Business and Consumption, BASIQ International Conference, p. 226–234.

Birkmann J. 2013. Measuring vulnerability to natural hazards: towards disaster resilient societies. 2nd ed. Tokyo: United Nations University Press.

Bocchini P, Frangopol DM. 2012. Restoration of bridge networks after an earthquake: Multicriteria intervention optimization. Earthquake Spectra. 28(2):427–455.

Bono F, Gutiérrez E. 2011. A network-based analysis of the impact of structural damage on urban accessibility following a disaster: the case of the seismically damaged Port Au Prince and Carrefour urban road networks. J Transport Geogr. 19(6):1443–1455.

Chen Y, Yu J, Khan S. 2013. The spatial framework for weight sensitivity analysis in AHP-based multi-criteria decision making. Environ Modell Software. 48:129–140.

Chunguang L, Huiying G. 2000. Reliability analysis of urban transportation system. In: Proceedings of the 12th World Conference on Earthquake Engineering, Auckland, New Zealand.

Colson G, De Bruyn C. 1989. Models and methods in multiple objectives decision making. Models and methods in multiple criteria decision making. 12: 1201–1211.

Douglas J. 2007. Physical vulnerability modelling in natural hazard risk assessment. Nat Hazards Earth Syst Sci. 7(2):283–288.

Fiedrich F. 2006. An HLA-based multiagent system for optimized resource allocation after strong earthquakes. In: Proceedings of the 2006 Winter Simulation Conference; p. 486–492.

Georgescu ES, Pomonis A. 2008. The Romanian earthquake of March 4, 1977 revisited: New insights into its territorial, economic and social impacts and their bearing on the preparedness for the future. In: Proceedings of the 14th World Conference on Earthquake Engineering, Beijing, China; p. 12–17.

Georgescu ES, Pomonis A. 2012. Building damage vs. territorial casualty patterns during the Vrancea (Romania) earthquakes of 1940 and 1977. In: Proceedings of the 15th World Conference on Earthquake Engineering, Lisboa, Portugal; p. 24–28.

Giardini D, Woessner J, Danciu L, Crowley H, Cotton F, Grünthal G, Pinho R, Valensise G, Akkar S, Arvidsson R, et al. 2013. Seismic Hazard Harmonization in Europe (SHARE): Online Data Resource, DOI: 10.12686/SED-00000001-SHARE.

Grozavu A, Patriche CV. 2021. Mapping landslide susceptibility at national scale by spatial multi-criteria evaluation. Geomatics Nat Hazards Risk. 12(1):1127–1152.

Hwang CL, Lai YJ, Liu TY. 1993. A new approach for multiple objective decision making. Comput Oper Res. 20(8):889–899.
Hwang CL, Yoon K. 1981. Methods for multiple attribute decision making. In: Multiple attribute decision making. Lecture notes in economics and mathematical systems. 186: 58–191. DOI: https://doi.org/10.1007/978-3-642-48318-9_3

Ismail-Zadeh A, Matenco L, Radulian M, Cloetingh S, Panza G. 2012. Geodynamics and intermediate-depth seismicity in Vrancea (the south-eastern Carpathians): current state-of-the art. Tectonophysics. 530–531:50–79.

Landes M, Fielitz W, Hauser F, Popa M, CALIXTO g. 2004. 3-D upper crustal tomographic structure across the Vrancea seismic zone, Romania. Tectonophysics. 382(1–2):85–102.

Lee S, Davidson R, Ohnishi N, Scawthorn C. 2008. Fire following earthquake—Reviewing the state-of-the-art of modeling. Earthquake Spectra. 24(4):933–967.

Marmureanu G, Popescu E, Popa M, Moldovan AI, Plăcintă AO, Radulian M. 2004. Seismic zoning characterization for the seismic hazard assessment in south-eastern Romania territory. Acta Geod Geophys Hung. 39(2–3):259–274.

McLafferty SL. 2003. GIS and health care. Annu Rev Public Health. 24(1):25–42.

Merciu C, Ianos I, Merciu GL, Jones R, Pomeroy G. 2018. Mapping accessibility for earthquake hazard response in the historic urban centre of Bucharest. Nat Hazards Earth Syst Sci. 18(7):2011–2026.

NIS (National Institute of Statistics). 2020a. Health related statistics. [accessed 2021 Dec 21]. http://statistici.insse.ro:8077/tempo-online/#/pages/tables/insse-table.

NIS (National Institute of Statistics). 2020b. Statistics on lifelines and territorial planning. [accessed 2022 Jan 3]. http://statistici.insse.ro:8077/tempo-online/#/pages/tables/insse-table.

NIS (National Institute of Statistics). 2021. Population and demographic structure statistics. [accessed 2022 Jan 14]. http://statistici.insse.ro:8077/tempo-online/#/pages/tables/insse-table.

Oaie G, Secriueru D, Seghedi A, Ioane D, Diaconescu M. 2006. Preliminary assessment of the tsunami hazard for the Romanian Black Sea area: historical and paleotsunami data. Geosciences. 200:300–302.

Oncescu MC, Marza VI, Rizescu M, Popa M. 2000. Vrancea earthquakes: tectonics, hazard and risk mitigation. Dodrecht: Kluwer Academic Publishers.

OpenStreetMap. (2021). [accessed 2021 Dec 18]. https://www.openstreetmap.org/#map=10/45.2768/27.8105

Pantea A, Constantin AP. 2011. Reevaluated macroseismic map of Vrancea (Romania) earthquake occurred on November 10, 1940. Rom J Phys. 56(3–4):578–589.

Pantea A, Constantin AP. 2013. Re-evaluation of the macroseismic effects produced by the March 4, 1977, strong Vrancea earthquake in Romanian territory. Ann Geophys. 56(1):104–116.

Papadopoulos GA, Diakogianni G, Fokaefs A, Ranguelov B. 2011. Tsunami hazard in the Black Sea and the Azov Sea: a new tsunami catalogue. Nat Hazards Earth Syst Sci. 11(3):945–963.

Pirvu R, Bădircă R, Manta A, Lupâncescu M. 2018. The effects of the cohesion policy on the sustainable development of the development regions in Romania. Sustainability. 10(7):2577.

Pitilakis K. 2011. Systemic seismic vulnerability and risk analysis for buildings. Lifeline networks and infrastructures safety gain. Deliverable. D2:12.

Radulian M. 2015. Mechanisms of Earthquakes in Vrancea. In: Beer M., Kougioumtzoglou I.A., Patelli E., Au SK. (eds) Encyclopedia of Earthquake Engineering. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-35344-4_302

Radulian M, Bala A, Popescu E, Toma-Danila D. 2018. Earthquake mechanism and characterization of seismogenic zones in south-eastern part of Romania. Ann Geophys. 61(1):108.

Rashed T, Weeks J. 2003. Assessing vulnerability to earthquake hazards through spatial multi-criteria analysis of urban areas. Int J Geogr Inf Sci. 17(6):547–576.

RDA (Regional Development Agency). 2014. The South-East Regional Development Plan 2014–2020 [In Romanian].

Rezaie F, Panahi M. 2015. GIS modeling of seismic vulnerability of residential fabrics considering geotechnical, structural, social and physical distance indicators in Tehran using multi-criteria decision-making techniques. Nat Hazards Earth Syst Sci. 15(3):461–474.
Ruan J, Wang X, Shi Y, Sun Z. 2013. Scenario-based path selection in uncertain emergency transportation networks. Int J Innovative Comput Inf Control. 9(8):3293–3305.
Saaty TL. 1977. A scaling method for priorities in hierarchical structures. J Math Psychol. 15(3):234–281.
Saaty TL. 2004. Decision making—the analytic hierarchy and network processes (AHP/ANP). J Syst Sci Syst Eng. 13(1):1–35.
Săgeată R. 2004. Human settlements systems and transfrontalier cooperation in the Prut catchment. Studii și Cercetări de Geografiă. p. 65–78. [In Romanian]
Săgeată R. 2007. Galați-Brăila Metropolitan area. A proposition. Comunicări de Geografie. p. 443–450. [In Romanian]
SE ROP (South-East Region Regional Operational Program). 2020. Annex 10291/19. ECOMP 2.B.
Tamima U, Chouinard L. 2017. Systemic seismic vulnerability of transportation networks and emergency facilities. J Infrastruct Syst. 23(4):04017032.
Toma-Danila D. 2018. A GIS framework for evaluating the implications of urban road network failure due to earthquakes: Bucharest (Romania) case study. Nat Hazards. 93(S1):97–111.
Toma-Danila D, Armas I, Tiganescu A. 2020. Network-risk: an open GIS toolbox for estimating the implications of transportation network damage due to natural hazards, tested for Bucharest, Romania. Nat Hazards Earth Syst Sci. 20(5):1421–1439.
Triantaphyllou E. 2000. Multi-criteria decision-making methods: a comparative study. Boston (MA): Springer US.
Triantaphyllou E, Shu B, Sanchez SN, Ray T. 1998. Multi-criteria decision making: an operations research approach. Encycl Electr Electron Eng. 15:175–186.
Țurcânașu G. Extinderea teritorială a orașelor Galați și Brăila și impactul asupra organizării spațiului. Reabilitarea și inserția funcțională a spațiului rural proxim într-o aglomerație urbană, Revista de politica stiintei și scientometrie, Chișinău 2005.
Ungureanu A. 1980. The cities of Moldavia. An Economic geography study [In Romanian], Editura Academiei Republicii Socialiste România
UTCB (Universitatea Tehnică de Construcții București). 2013. Seismic design code. Part 1: Provisions for the design of buildings. Indicative P-100/1 [In Romanian]. Elaborated by UTCB, endorsed by MDRAP Official Journal of Romania. Code O100-1/2013. Bucharest, Romania: UTCB.
Vacareanu R, Pavel F, Aldea A. 2013a. On the selection of GMPEs for Vrancea subcrustal seismic source. Bull Earthquake Eng. 11(6):1867–1884.
Vacareanu R, Lungu D, Marmureanu G, Cioflan C, Aldea A, Arion C, Demetriu S, Pavel F. 2013b. Statistics of seismicity for Vrancea subcrustal source. In: Proceedings of the International Conference on Earthquake Engineering SE-50 EEE, Skopje, Macedonia, Paper No. 138.
Walker BB, Taylor-Noonan C, Tabbernor A, McKinnon T, Bal H, Bradly D, Schuurman N, Clague JJ. 2014. A multi-criteria evaluation model of earthquake vulnerability in Victoria, British Columbia. Nat Hazards. 74(2):1209–1222.
Yi W, Kumar A. 2007. Ant colony optimization for disaster relief operations. Transp Res Part E: Logist Transp Rev. 43(6):660–672.
Zaytsev A, Pelinovsky E, Yalciner A, Ionescu C, Iren M. 2015 Apr. Assessment of Tsunami hazard for western coast of the Black sea. In: EGU General Assembly Conference Abstracts, p. 10262.