

Flood hazard and vulnerability-related research in Romania. The Gordian knot of conceptual and operational overlapping

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Abstract. Scientific research is of critical importance for salient decision-making aiming to reduce flood risk, but the interwoven character of risk-related terminology and the demanding task of operationalising concepts like hazard and vulnerability frequently hinder scientific advancement. This paper documents the i) meaning of the terms hazard and vulnerability, and ii) operationalisation of these concepts, in the scientific research focusing on river floods in Romania. A 4-step semi-systematic literature review was performed, setting the time frame to 2000-2022. The literature review points out the conceptual and operational overlapping of the flood hazard and vulnerability, as well as their dynamics and spatial focus. Flood hazard is operationalised mostly through hydraulic modelling and spatial analysis, while flood vulnerability is frequently assessed via index-based methodologies. There are several studies that operationalise flood vulnerability or hazard using a methodology that targets flood risk. Another tendency observed in the literature is to choose titles referring to one of the flood risk components, but to formulate aims that concern the other; in certain cases only to assess their intersection. By addressing these issues, we aim to open the way to flood hazard and/or vulnerability assessments that properly fit the terminological and methodological paradigms.

Keywords: flood hazard, flood vulnerability, risk terminology, Romania flood

1. INTRODUCTION

Floods represent prevalent, high-impact natural hazards that can easily lead to disasters or crisis situations, given the appropriate vulnerability conditions. Flood events were estimated to account for approximately 0.5 billion deaths, also affecting over 2.8 billion people in 1980-2009 (Doocy et al. 2013), and 2 billion people in 1998-2017 (WHO 2020). Optimistic perspectives are shown by the decrease in flood-determined fatalities in 1960-2013 (Tanoue et al. 2016), but the impact of future floods may be augmented by climate change (Mandel et al. 2021), in conjunction with increased exposure of population and assets (Rentschler et al. 2022). Another factor worth considering refers to the economic, social, and health impact of the Covid-19 pandemic, which hindered the management of the 491 flood-related disasters reported worldwide during the first two and a half years of the pandemic (Albulescu et al. 2022).

Against this background, flood-related research proves critical, as flood management and decision-making should be grounded on scientific findings. In this context, a proper understanding of the risk-related terminology is a prerequisite not only for research aligned to international standards, but also for the efficient elaboration of flood mitigation plans and flood risk reduction strategies.

Nevertheless, there are two notable challenges that arise in any research effort concerning natural risks. The first refers to the intricate and wide-range definitions of risk terminology, which stem from the integration of the risk, hazard, and vulnerability terms many scientific disciplines, each with its own definitions, ontology, and methodological approach (Hufschmidt 2011). This leads to semantic fragmentation, scientific inconsonances and transform comparisons into puzzling tasks. The second challenge consists in the conundrum of operationalising the risk, hazard and vulnerability concepts.

This paper aims to document the i) meaning of the hazard and vulnerability terms related to floods, and ii) operationalisation of these concepts, in the scientific research published in 2000-2022, focusing on river floods in Romania. The study area was selected based on its significant flood risk that results from the intersection of high-level flood hazard and vulnerability (FHV). Liu et al. (2022) place Romania on the 30th place in the world in terms of flood frequency, and the fact that more than half of the disasters registered in 1990-2016 are linked to flood events (Zaharia and Ioana-Toroimac 2017) proves that the country displays strong vulnerability conditions.

This is the first literature review that focuses on the use of risk-related terminology in Romania. It contributes to our understanding of the Romanian perspective on FHV, and may represent a source of future research ideas. In addition, it helps to identify convergence points and inconsonances between place- or scale-dependent research perspectives and the internationally accepted terminology.

2. RISK-RELATED TERMINOLOGY

The terms that are most subject to divergent definition and implicitly various operationalisation approaches are risk, hazard, and vulnerability; these are complemented by resilience, exposure, susceptibility/sensitivity, etc.

Risk is defined as “the potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society or a community in a specific period of time, determined probabilistically as a function of hazard, exposure, vulnerability and capacity” (UNDRR 2022). The elements of the aforementioned function may vary (Villagran de Leon 2006), but the ones that are indispensable to any definition are hazard and vulnerability, which also support multiple interpretations.

A hazard designates a “process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation” (UNDRR 2022), but it is also viewed as the probability of occurrence of such a process or phenomenon in a certain region and time frame (Cardona 2003, Birkmann et al. 2014).

The term vulnerability presents an even wider palette of definitions, as shown by numerous literature review papers (Adger 2006, Villagran de Leon 2006, Fuchs et al. 2011, Hufschmidt, 2011). The definition evolved from the factor of internal risk to a multidimensional concept (Birkmann 2013). The first stages of evolution focus on the dimensions of potential loss and damage (supported by the elements at risk) caused by the manifestation of a hazard (Coburn et al. 1994), while the multifaceted and dynamic attributes of the concept are best portrayed by the UNDRR (2022) definition: vulnerability is the totality of “conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards”. This definition relies on susceptibility, which represents the tendency of a certain area to be affected by a phenomenon with destructive potential (Dominguez-Cuesta 2013).

In this paper, all the terms in risk research are integrated into river floods and flash floods contexts, and the definitions provided by the United Nations Disaster Risk Reduction Glossary (UNDRR 2022) are held as standard, internationally accepted ones.

3. METHODOLOGY

The semi-systematic literature review concerning the FHV research in Romania was a 4-step process (Figure 1), coordinated by the following research questions:

- How are the FHV concepts defined/interpreted and operationalised in the autochthonous scientific literature?
- How did the FHV operationalisation evolve in time (2000-2022)?
- Are the autochthonous operationalisations concordant with the international, official definitions of risk-related terminology?

Both risk components were reviewed by introducing specific keywords (i.e., “flood hazard Romania”, “flood vulnerability Romania”) into academic search engines (e.g., Google Scholar, Web of Knowledge, ResearchGate). At this stage, a total of 44 papers written in English were collected, each of them including “hazard”, “vulnerability”, or

“susceptibility” in their title or keyword list, concurrently stating the aim of assessing the risk components mentioned above in a “flood” and/or “flash-flood” context.

The exclusion criteria referred to the relevance of the research topics for the operationalisation of the FHV. For instance, scientific papers concerning soft and hard flood hazard mitigation methods, as well as particular flood hazard events were excluded from the literature review, due to the fact that they do not add to the operationalisation of the FHV. Papers referring to dam failure and associated flood modelling were also left out of the review, because they focus on flood risk and not particularly on one of its components. Subsequently, assessments that consider other destructive processes and phenomena in addition to floods, were excluded from the list, since the review concerns specifically flood hazard or vulnerability. Finally, the papers that did not meet basic academic standards (i.e., organised structured, well-explained methodological framework, reproducible results) were deleted from the list of considered research works. To gain as broad a perspective as possible, the type of paper (e.g., literature review, research article, technical note/report) or the journal metrics were not included on the list of exclusion criteria.

The resulting batch of 28 articles was thoroughly read and analysed, comparing their findings with the official definitions of hazard and vulnerability. In addition, a database of indicators integrated in flood vulnerability assessments was constructed (Appendix 1).

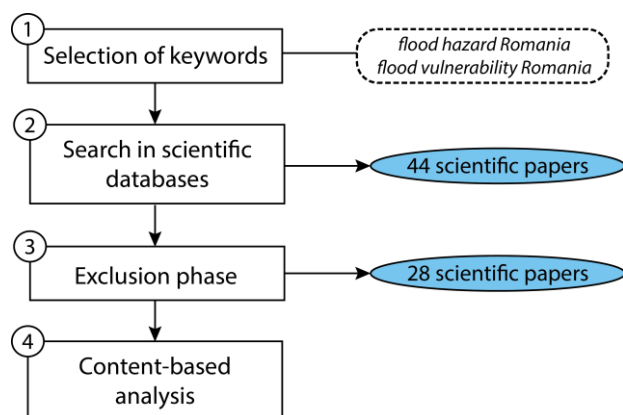


Figure 1. Methodological workflow of the literature review

4. RESULTS

Research on flood hazard

The number of selected articles concerning flood and/or flash flood hazard is rather low (8), due to the fact that only the ones that specifically use the term hazard in their title, aim or keyword list were included. The papers with titles that exclude the term of interest, but comprise “flood/flash flood potential” were considered to refer to flood risk, and not specifically to the flood hazard. Half of the research papers were published since 2019, and only two of them were written during the Covid-19 pandemic (Figure 2). The scale of flood hazard analysis varies from national level (Mătreacă et al. 2016) to catchment level (e.g., the lower course of the Siret, the watersheds of the Buzău, Trotuş, Niraj, Bâsca Chiojdului rivers). There are also studies that mapped flood hazard at landform unit scale (Hutanu et al. 2020) or in urban and peri-urban areas (Mihu-Pintilie et al. 2019).

The narrow batch of papers and the fact that the earliest paper of this type dates back to 2014 indicate that the hazard concept is still in its emergent stage in the Romanian scientific literature concerning floods. This evolution phase is characterised by confusion and misinterpretation of the term (Figure 2), which are highlighted by the fact that certain titles include “hazard”, but the aim of the paper refers to flood vulnerability assessment (Roşca et al. 2014, Mihu-Pintilie et al. 2019, Popa et al. 2019, Hutanu et al. 2020). Also, none of the analysed manuscripts include definitions of the flood hazard.

Generally, flood and/or flash-flood hazard is analysed in terms of probability of occurrence (Roşca et al. 2014), flood extent, water depth, water elevation profiles for 10 to 100-year flood events (Țincu et al. 2018, Mihu-Pintilie et al. 2019, Arseni et al. 2020), or runoff thresholds (Mătreacă et al. 2016). Correct operationalisation approaches of flood hazard rely on hydraulic modelling and analysis via software designed to perform one or two-dimensional hydraulic calculations (e.g., HEC-RAS) (Mihu-Pintilie et al. 2019, Arseni et al. 2020, Hutanu et al. 2020), but there are also approaches that use the runoff coefficient (Mătreacă et al. 2016),

or statistical and spatial analysis models (Roşca et al. 2014, Țîncu et al. 2018). However, only few of these studies include validation procedures (Costache and Zaharia 2017, Hutănu et al. 2020); which constitutes a methodological weakness.

In some cases, flood hazard is analysed together with flood risk (Roşca et al. 2014, Țîncu et al. 2018, Arseni et al. 2020), but there are also studies where hazard is operationalised as risk (Mihu-Pintilie et al. 2019, Popa et al. 2019). This deviation from proper assessment procedures is determined by the introduction of exposure-related elements in the assessments (Mihu-Pintilie et al. 2019), or by

integrating both hazard and vulnerability indicators into the Flood and Flash-Flood Potential Index (Popa et al. 2019). On the other hand, Costache and Zaharia (2017) use only site-related vulnerability indicators (which make up the Flash-Flood Potential Index) to assess flood hazard, which means that the operationalisation of the hazard actually targets vulnerability (Figure 2). Another deviation from the norm constitutes the validation of the runoff coefficient-based hazard assessment using the Flash-Flood Potential Index, which integrates vulnerability-related indicators (Mătreacă et al. 2016).

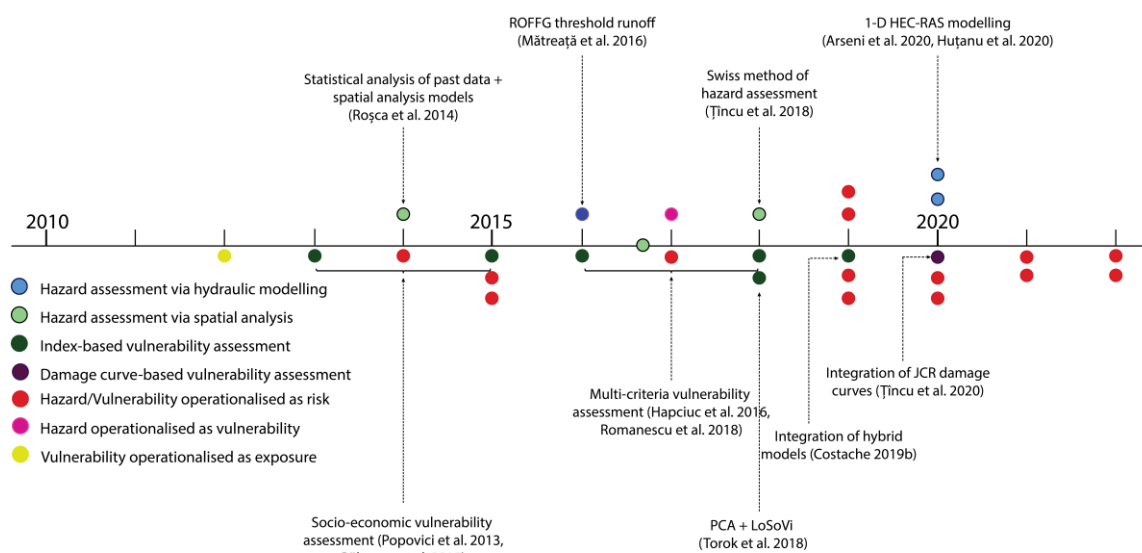


Figure 2. Timeline of the operationalisation variants of flood hazard and vulnerability

Research on flood vulnerability

Research concerning vulnerability to floods and/or flash floods also emerged relatively recently, the first article on the chronologically-ordered list of analysed research works dating back to 2012. Half of the 20 papers were written in 2019-2022, and 6 of them correspond to the pandemic period (Figure 2). The selection of the study areas seem to be motivated by the interest and affinity of the authors, and also by the incidence of flood events. Few studies focus on landform units (Popovici et al. 2013, Bălăteanu et al. 2015, Iosub et al. 2020), and even fewer choose the national scale for the assessment of flood vulnerability (Török 2018); meaning that catchment scale was preferred. The

watersheds of the Prahova (Costache 2019a), Moldova (Popa et al. 2020), Jijia (Iosub et al. 2020), Sucevița (Hapciuc et al. 2016, Romanescu et al. 2018), Putna (Costache and Bui, 2019), Trotuș (Țîncu et al. 2020) rivers are just several of the study areas subject to flood vulnerability assessment.

The multidimensionality of vulnerability leads to a variety of ways to define and operationalise this concept. The UNDRR (2022) definition highlights the susceptibility of human communities to be affected by hazards, but it does not mention exposure, which is viewed as part of vulnerability by some scientists (Willroth et al. 2011, Birkmann 2013). Also, the coping capacity of the human communities, together with other closely related

concepts (i.e., adaptation, adjustment) are left out of the official definition, although these may alter the vulnerability level (Smit and Wandel 2006). In this literature review, all the aforementioned interpretation options were identified and analysed in direct relation to the operationalisation approaches. It has to be highlighted that in some cases, vulnerability was interpreted only using its susceptibility component, which motivates the inclusion of papers that refer to flood susceptibility in the literature review.

As vulnerability cannot be directly measured, its operationalisation in flood and/or flash flood hazard contexts, relies on indices that are aggregated in weighted or non-weighted indexes (Figure 2). The most common indicators correspond to site-related vulnerability of geological, morphological, hydrological, or pedological nature, but the pool of analysed articles also included indicators of building, socio-economic, and environmental vulnerability (Appendix 1). It should be highlighted that the values of these indicators may increase or decrease the vulnerability level, therefore partially matching the UNDRR (2022) definition which focuses on the factors or processes that increase susceptibility to harm. For example, the distance from a river may be long enough to ensure the safety of a particular building during a flood event, or too short and associated with an increased vulnerability level.

In some cases, the index-based methodologies are complemented by multi-criteria analysis (Hapciuc et al. 2016, Romanescu et al. 2018, Popa et al. 2020), and all the studies use GIS for spatial modelling and visualisation. The use of software designed to perform hydraulic calculations (e.g., HEC-RAS) is limited in flood vulnerability assessments (Romanescu et al., 2018). Another approach is to assess vulnerability based on damage curves that integrate water depth thresholds (Țincu et al. 2020).

Like in the case of flood hazard-related studies, a prominent methodological issue concerns the validation of the results, which is often omitted (Cheveresan 2012, Popovici et al. 2013, Prăvălie and Costache 2014, Bălțeanu et al. 2015, Costache et al. 2015, Zaharia et al. 2015, Hapciuc et al. 2016,

Török 2018, Iosub et al. 2020, Popescu and Bărbulescu 2022).

The Romanian scientific literature on floods and flash flood vulnerability includes many examples where the purpose of assessing vulnerability is associated with a methodological framework that targets a different concept. This overlap takes the following forms:

- Vulnerability (often referred to as susceptibility) is assessed using a methodology that targets flood risk (Prăvălie and Costache 2014, Zaharia et al. 2015, Costache 2017, 2019, Costache et al. 2015, 2019a, 2021, Costache and Bui 2019, Iosub et al. 2020, Popa et al. 2020, Stoica-Fuchs 2021, Kocsis et al. 2022, Popescu and Bărbulescu, 2022). For instance, the Flood Potential Index (FPI), although it is defined as the occurrence potential of floods by Costache et al. (2015) – which matches the flood hazard definition of Cardona (2003), includes both susceptibility indicators and hazard indicators, making it a flood risk index. The same conceptual overlap between flood hazard and susceptibility, and risk-related operationalisation is illustrated by the Flood Susceptibility Index (Prăvălie and Costache 2014). The integration of both vulnerability/ susceptibility and hazard indicators, in the endeavour to assess the former, is also specific to the Flash Flood Susceptibility Index (Popescu and Bărbulescu 2022), the Flash Flood Potential Index (Zaharia et al. 2015, Costache 2017, Popa et al. 2020, Kocsis et al. 2022), and the Flood Potential Index (Zaharia et al. 2015, Costache 2019a), or to the approaches that combine machine learning or deep learning models (Costache et al. 2021). In many cases, these indexes integrate the amount or the intensity of rainfall, which relates to one of the factors that contribute to flood hazard, and not to vulnerability. This is because large amounts of rainfall do not make certain spaces or human communities more vulnerable to floods, but increase the probability of flood occurrence.

In addition, there are articles that aim to identify elements exposed to flash flood risk and use methodological frameworks consistent with this purpose, but that have titles relating to the

assessment of flash flood susceptibility potential (Iosub et al. 2020).

- Vulnerability is interpreted only as exposure (Cheveresan 2012), as its operationalisation is performed only through exposure indicators and does not include factors or processes that increase flood susceptibility.

A particular situation encountered in the autochthonous literature on flood vulnerability consists of correct operationalisation in the context of an erroneous definition of the concept. Costache (2019b) uses the Flash-Flood Potential Index, which integrates site-related vulnerability indicators, but refers to these as flash-flood conditioning factors, therefore attributing them to the hazard. It should be noted that the name of the index relates to flood risk, and that its selection for the purpose of vulnerability assessment deviates from the norm.

Nonetheless, there are multiple papers that define vulnerability in a proper manner (Popovici et al. 2013, Bălteanu et al. 2015, Romanescu et al. 2018), or that use the term correctly even without defining it, at the same time operationalising it adequately (Hapciuc et al. 2016, Török 2018).

5. CONCLUSIONS

The literature review points out the conceptual and operational overlap of FHV, as well as their dynamics over the last two decades (2000-2022), and the spatial focus of flood risk-related studies.

The limitations of this paper concern the exclusion of relevant research works of greater extent (e.g., doctoral theses), and of older papers that may not be available online. However, the literature review stands out as the first of its type, and allows for a deeper understanding of the ways FHV are interpreted and operationalised in the autochthonous scientific literature. Moreover, it can be a source of inspiration for future research works concerning the topic of interest.

Returning to the research questions of this study, it appears that the Romanian scientific literature includes both correct and incorrect interpretations and operationalisation approaches of the FHV

concepts. The fitness of the conceptualisation and operationalisation steps within the internationally accepted research framework concerning FHV is not time dependent, as the correct interpretations and methodological frameworks alternate with those that deviate from the paradigm (Figure 2).

There are studies that operationalise flood hazard as risk, while others confuse hazard with vulnerability. In return, some flood vulnerability assessments are performed using both hazard and vulnerability indicators, meaning that they actually target flood risk. A distinctive tendency is to avoid the use of hazard or vulnerability terms, in favour of confusing terminology like “flood potential” or “flood susceptibility potential”. Also, the use of Flood or Flash-Flood Potential Index seems to be a common methodological issue of many studies that aim to analyse one of the components of flood risk, but end up constructing this index based a range of indicators that do not fit the stated research purpose. All of these examples suggest a shallow understanding of the FHV concepts.

Considering the interwoven character of risk-related terminology and its associated sense-related traps, the deviant interpretations and operationalisation approaches lead to an even more convoluted maze of risk-related research. In this context, the comparison of autochthonous findings with ones obtained in other regions of Europe or the world, becomes a fruitless effort. By bringing to light these issues, we aim to encourage flood hazard and/or vulnerability analyses that suit the terminological and methodological paradigms.

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APPENDIX 1

Table 1. Flood vulnerability indicators selected from the autochthonous scientific literature

Type of vulnerability	Indicator	Reference(s)
Site-related vulnerability	Elevation	Prăvălie and Costache (2014), Costache et al. (2015), Costache (2017, 2019a, b), Costache and Bui (2019), Costache et al. (2021), Kocsis et al. (2022)
	Slope	Prăvălie and Costache (2014), Costache et al. (2015), Zaharia et al. (2015), Hapciuc et al. (2016), Costache (2019a, b), Costache and Bui (2019), Popa et al. (2020), Costache et al. (2021), Kocsis et al. (2022), Popescu and Bărbulescu (2022)
	Length-Slope (L-S)	Zaharia et al. (2015), Costache (2017), Popa et al. (2020), Kocsis et al. (2022), Popescu and Bărbulescu (2022)
	Aspect	Costache (2017, 2019b), Costache and Bui (2019), Popa et al. (2020), Costache et al. (2021), Kocsis et al. (2022)
	Curvature/Plan curvature	Costache (2019a, b), Costache and Bui (2019), Costache et al. (2021), Popescu and Bărbulescu (2022)
	Profile curvature	Zaharia et al. (2015), Hapciuc et al. (2016), Costache (2017, 2019a), Costache and Bui (2019), Kocsis et al. (2022)
	Depth of fragmentation	Kocsis et al. (2022)
	Lithology	Prăvălie and Costache (2014), Costache et al. (2015), Zaharia et al. (2015), Hapciuc et al. (2016), Costache (2019a, b), Costache and Bui (2019), Costache et al. (2021), Kocsis et al. (2022), Popescu and Bărbulescu (2022)
	Hydrological soil groups	Costache (2019a, b), Costache and Bui (2019), Iosub et al. (2019), Popa et al. (2020), Costache et al. (2021), Kocsis et al. (2022)
	Soil type	Kocsis et al. (2022)
	Soil texture	Prăvălie and Costache (2014), Zaharia et al. (2015), Hapciuc et al. (2016), Popescu and Bărbulescu (2022)
	Soil erodibility by water	Popa et al. (2020)
	Topographic Wetness Index	Costache (2019a, b), Costache and Bui (2019), Costache et al. (2021), Kocsis et al. (2022)
	Topographic Position Index	Costache (2019b), Costache and Bui (2019), Costache et al. (2021), Kocsis et al. (2022)
	Land use/land cover	Prăvălie and Costache (2014), Zaharia et al. (2015), Hapciuc et al. (2016), Costache (2019a, b), Costache and Bui (2019), Popa et al. (2020), Costache et al. (2021), Kocsis et al. (2022), Popescu and Bărbulescu (2022)
	Distance from the river	Romanescu et al. (2018), Costache (2019a), Costache and Bui (2019), Costache et al. (2021)
	Drainage density	Costache et al. (2015), Zaharia et al. (2015), Popa et al. (2020)
	Presence of hydroengineering works	Romanescu et al. (2018)
Building vulnerability	Material of construction (buildings)	Popovici et al. (2013), Romanescu et al. (2018), Török et al. (2018)
	Building condition	Romanescu et al. (2018)
	Use of building	Romanescu et al. (2018)
Socio-economic vulnerability	Total no. of inhabitants in the affected area	Cheveresan (2012)
	Population density	Török et al. (2018)
	Average no. of people/household	Török et al. (2018)
	Density of housing units	Török et al. (2018)
	Percentage/total number of children	Cheveresan (2012), Popovici et al. (2013), Bălteanu et al. (2015), Török et al. (2018)

Type of vulnerability	Indicator	Reference(s)
	Percentage/total population of elderly	Cheveresan (2012), Popovici et al. (2013), Bălteanu et al. (2015), Török et al. (2018)
	Demographic dependency ratio	Török et al. (2018)
	No. of births/1000 inhabitants	Török et al. (2018)
	Net international migration rate	Török et al. (2018)
	Percentage of women	Török et al. (2018)
	Percentage of widow women	Török et al. (2018)
	Percentage of roma population	Popovici et al. (2013), Bălteanu et al. (2015), Török et al. (2018)
	Percentage of Hungarian ethnics	Popovici et al. (2013)
	Illiteracy rate	Török et al. (2018)
	No. of students/teacher	Popovici et al. (2013)
	Percentage of gymnasium graduates	Bălteanu et al. (2015)
	Percentage of university graduates	Popovici et al. (2013), Török et al. (2018)
	No. of doctors/1000 inhabitants	Bălteanu et al. (2015)
	No. of hospital beds per capita	Popovici et al. (2013)
	Percentage of disabled people	Popovici et al. (2013)
	Average household income	Popovici et al. (2013)
	Per capita income	Török et al. (2018)
	Employment rate	Török et al. (2018)
	Percentage of unemployment	Popovici et al. (2013), Bălteanu et al. (2015)
	Tax collection rate at local budget	Török et al. (2018)
	Percentage of people dependent on social benefits	Popovici et al. (2013)
	Entrepreneurial activity rate	Török et al. (2018)
	Percentage of service employees	Török et al. (2018)
	Percentage of agriculture employees	Bălteanu et al. (2015)
	Percentage of income from agriculture	Popovici et al. (2013)
	Herfindahl-Hirschman Index	Bălteanu et al. (2015)
	Amount of drinking water supplied to consumers	Bălteanu et al. (2015)
	Percentage of household with access to the public water supply	Popovici et al. (2013)
	Share of households with different facilities (access to piped water, sewage network, heating system, kitchen area, fixed bath)	Török et al. (2018)
	Total number of affected houses	Cheveresan (2012)
	Total number of affected roads, railways	Cheveresan (2012)
	Road density	Popovici et al. (2013), Bălteanu et al. (2015)
	Access to major public roads, railways	Török et al. (2018)
	Total number of affected domestic animals	Cheveresan (2012)
	No. of cultural heritage sites	
Environmental vulnerability	No. of protected areas	Popovici et al. (2013)
	Surface of protected areas	Cheveresan (2012)
	Ha of areas exposed to contamination because of na-tech hazards	Popovici et al. (2013)
	Total no. of landfill deposits in the affected area	Cheveresan (2012)

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