Dear Editor,

Thank you very much for your summary of the reviewers' comments. We are grateful for your thorough assessment of our manuscript. To respond to your comments, we have used a colour code: your comments and questions already solved are in grey and our respective answers in black. The corresponding paragraph in the paper is dark blue.

Comments

- As you know, two reviewers have now provided detailed reviews, which you have replied in detail to. Despite the fact that, that one reviewer recommended to reject your manuscript, I offer the possibility to revise the manuscript. I find your topic very interesting and I am optimistic, that you will be able to significantly and sufficiently improve your manuscript with major revision. However, I expect that quite some effort is necessary.

  We appreciate the opportunity to revise our manuscript. We are confident that we have addressed this important topic by following the comments from you and your reviewers The revision required quite a lot of effort, but the result is a more consistent paper.

- One major critique is, that both reviewer doubt that you identified all relevant papers for your research question and focus of review. Of course, the selection of key words for the search are your decision, however, it is also your responsibility to make sure that you identify all relevant papers with your selection of key words.

  Thanks for this observation. Following this comment and the comments of the reviewers, we decided to re-run the search query, updating the time period for the systematic review from 2008-2018 to 2010 – 2020. The reason to update the time period is that in this systematic review we are interested in knowing the state of the art in data sources, spatial variables, indicators, methods, indexes and tools for the assessment of the socio-economic vulnerability (SEV) related to geohazards, which we consider is covered in the last ten years.

  To ensure that we identified all relevant papers for our research question, this time we undertook the search not only in Clarivate but also in two more databases: Scopus/Elsevier and Google Scholar. Additionally, to the different names for socio-economic vulnerability (SEV), and spatial variables, we added the complete list of geohazards that we are interested in this research to the query: "earthquakes" OR "tsunamis" OR "volcanic eruptions" OR "landslides" OR "soil erosion" OR "land degradation". Following the request of the reviewers, we included in this revised version the table with the terms included and excluded to select relevant literature reference, that was not included in the previous version as a suggestion of the second co-author. Please find the search terms considered in Table 1.

D	Q	SEARCH TERMS
Clarivate analytics	TOPIC	"social vulnerability" OR "economic vulnerability" OR "socioeconomic vulnerability" OR "socio-economic vulnerability"
		AND

D	Q	SEARCH TERMS
	TOPIC	“area” OR “distance” OR “range” OR “distance” OR “direction” OR “spatial geometries” OR “patterns” OR “spatial connectivity” OR “isolation” OR “diffusion” OR “spatial association” OR “scale” OR “accessibility” OR “network” OR “cluster”
		AND
	TOPIC	“earthquakes” OR “tsunamis” OR “volcanic eruptions” OR “landslides” OR “soil erosion” OR “land degradation”
		NOT
	TOPIC	“climate change” OR “ecological” OR “drought” OR “resilience” OR “debris” OR “epidemiological” OR “substance” OR “behavioural” OR “evacuation” OR “recovery” OR “pollution” OR “leptospirosis” OR “violence” OR “illness” OR “disease” OR “heat” OR “crisis” OR “conflict” OR “deaths” OR “obesity” OR “criminal” OR “chemical” OR “symptoms” OR “syndrome” OR “food insecurity” OR “air pollution” OR “stress” OR “diabetes” OR “depressive” OR “alcohol” OR “cancer” OR “drugs” OR “palm oil” OR “tobacco” OR “smoke” OR “storm” OR “psychometric” OR “cocaine” OR “toxic” OR “palliative” OR “therapy” OR “HIV” OR “dengue” OR “ecosystem” OR “rheumatoid” “arthritis” OR “nutritional” OR “malaria” OR “resources” OR “sexual activity” OR “sexual health”
Scopus/Elsevier	Article title, abstract, keywords	(TITLE-ABS-KEY (“social vulnerability*” AND “economic vulnerability*”) AND TITLE-ABS-KEY (“socioeconomic vulnerability*”) AND TITLE-ABS-KEY (“area” OR “distance” OR “range” OR “distance” OR “direction” OR “spatial geometries” OR “patterns” OR “spatial connectivity” OR “isolation” OR “diffusion” OR “spatial association” OR “scale” OR “accessibility” OR “network” OR “cluster”) AND TITLE-ABS-KEY (“earthquakes” OR “tsunamis” OR “volcanic eruptions” OR “landslides” OR “soil erosion” OR “land degradation”) AND NOT TITLE-ABS-KEY (“climate change” OR “ecological” OR “drought” OR “resilience” OR “debris” OR “epidemiological” OR “substance” OR “behavioral” OR “evacuation” OR “recovery” OR “pollution” OR “leptospirosis” OR “violence” OR “illness” OR “disease”)) AND DOCTYPE (ar) AND PUBYEAR > 2009 AND PUBYEAR <2021

D: Database
Q: Query

Table 1. Terms included and excluded to select relevant literature references in Clarivate analytics.

Google scholar was discarded as a source of references given that when the query was run on this database, it provided only one reference, which was the first version of this manuscript. Please see the evidence below in Figure 1.

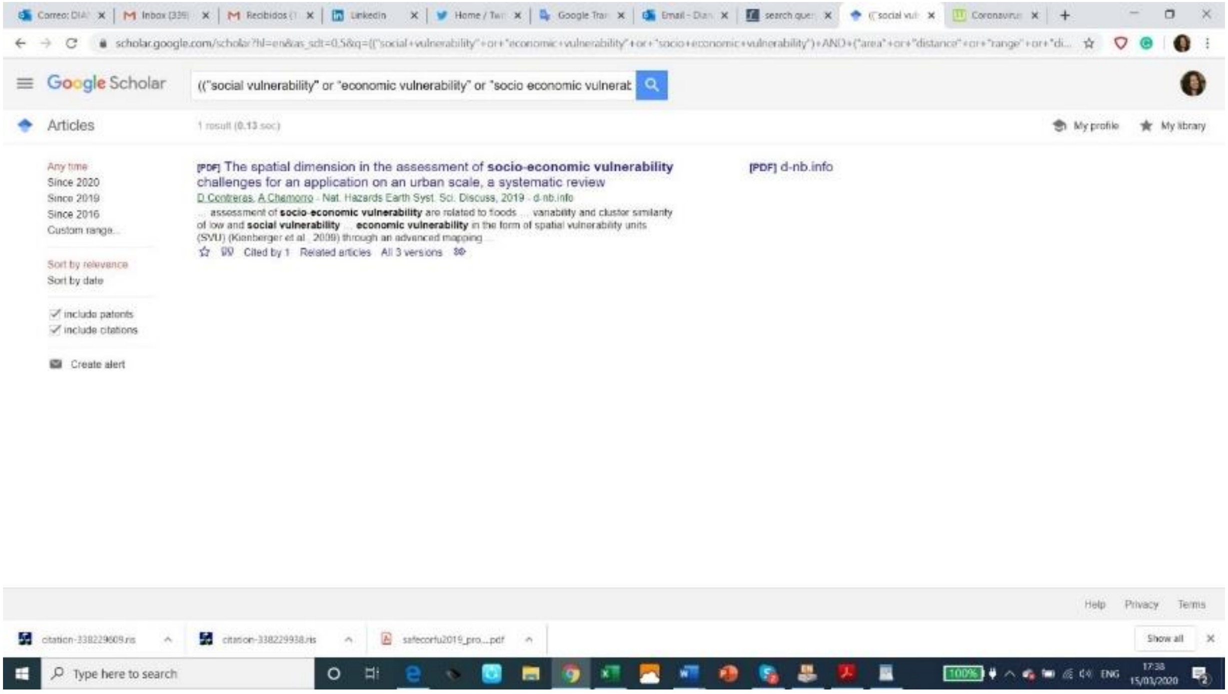

Figure 1. Evidence of the result of the query on the Google Scholar database.

- Since you want to provide a stat of the art review, I don't think that it is a good idea to exclude all most recent papers, i.e. the ones published after 2018. Additionally, I suggest that you also present results of key papers, which were published before 2008, maybe in a sort of background or in the introduction chapter.

Thank you for your suggestion. We could not agree more with this observation. In consequence, we decided to re-run the search query, updating the time period for the systematic review from 2008-2018 to 2010 – 2020. This time the search query allowed us to identify five references published after 2018:

- Aksha, S. K., Resler, L. M., Juran, L., & Carstensen, L. W. (2020). A geospatial analysis of multi-hazard risk in Dharan, Nepal. Geomatics Natural Hazards & Risk, 11(1), 88-111. doi:10.1080/19475705.2019.1710580
- Kurnianto, F. A., Ikhsan, F. A., Apriyanto, B., & Nurdin, E. A. (2019). Earthquake vulnerability disaster in the Lembang district of West Bandung Regency, Indonesia. Earthquake Science, 32(1), 40-46. doi:10.29382/eqs-2019-0040-5
- Muir, J. A., Cope, M. R., Angeningsih, L. R., Jackson, J. E., & Brown, R. B. (2019). Migration and Mental Health in the Aftermath of Disaster: Evidence from Mt. Merapi, Indonesia. International Journal of Environmental Research and Public Health, 16(15), 19. doi:10.3390/ijerph16152726
- Rezaei-Malek, M., Torabi, S. A., & Tavakkoli-Moghaddam, R. (2019). Prioritizing disaster-prone areas for large-scale earthquakes' preparedness: Methodology and application. Socio-Economic Planning Sciences, 67, 9-25. doi:10.1016/j.seps.2018.08.002
- Yuan, H. H., Gao, X. L., & Qi, W. (2019). Fine-Scale Spatiotemporal Analysis of Population Vulnerability to Earthquake Disasters: Theoretical Models and Application to Cities. Sustainability, 11(7), 19. doi:10.3390/su11072149

This time the oldest references are from 2012 and they are only two, one identified with the current refined search query and another identified in the previous search. Following your suggestion, we also reviewed relevant references published before 2008 such as:

- Adger, W. N., Brooks, N., Bentham, G., Agnew, M., and Eriksen, S.: New indicators of vulnerability and adaptive capacity, Tyndall Centre for Climate Research Technical Report 7, 2004.
- Bedimo-Rung, A. L., Mowen, A. J., and Cohen, D. A.: The significance of parks to physical activity and public health: A conceptual model, American Journal of Preventive Medicine, 28, 159-168, 2005
- Bell N, Schuurman N, Oliver L, and MV, H.: Towards the construction of place-specific measures of deprivation: a case study from the Vancouver metropolitan area. , Can Geogr 51, 444–461, 2007.
- Birkmann, J.: Indicators and criteria for measuring vulnerability: theoretical bases and requirements. In: Measuring Vulnerability to Natural Hazards. Towards Disaster Resilient Societies, Birkmann, J. (Ed.), United Nations University Press, Tokyo, 2006
- Béné, C.: Are Fishers Poor or Vulnerable? Assessing Economic Vulnerability in Small-Scale Fishing Communities, The Journal of Development Studies, 45, 911-933, 2009.
- Cardona, O. D.: Indicators of Disaster Risk and Risk Management: Program for Latin America and the Caribbean: Summary Report, Inter-American Development Bank, Washington, DC, USA, 2005.
- Chambers, R.: Vulnerability, coping and policy, IDS Bulletin, 20, 1-7, 1989.
- Clark, G. E., Moser, S. C., Ratick, S. J., Dow, K., Meyer, W. B., Emani, S., Jin, W., Kasperson, J. X., Kasperson, R. E., and Schwarz, H. E.: Assessing the Vulnerability of Coastal Communities to Extreme Storms: The Case of Revere, MA., USA, Mitigation and Adaptation Strategies for Global Change, 3, 59-82, 1998.
- Deichmann, U.: Accessibility Indicators in GIS, United Nations Statistics Division, Department for Economic and Policy Analysis, New York, NY, USA, 1997.
- Ebert, A., Kerle, N., and Stein, A.: Urban social vulnerability assessment with physical proxies and spatial metrics derived from air- and spaceborne imagery and GIS data, Nat. Hazards, 48, 275-294, 2009.
- Esty, D., Levy, M., Srebotnjak, T., and De Sherbin, A.: Environmental Sustainability Index, Yale Center for Environmental Law and Policy New Haven, CT, USA, 2005.
- Fekete, A.: Validation of a social vulnerability index in context to river-floods in Germany, Nat. Hazards Earth Syst. Sci., 9, 393-403, 2009
- Goncalves, M. and Vizintim, M. F. B.: Geographical features of the state of Parana in the face of natural disasters, Confins, 33, 25, 2017.
- Goodall, B.: The Penguin dictionary of human geography, Penguin Books, Harmondsworth, Middlesex, England; New York, N.Y., U.S.A., 1987.
- Grace, K. L. L. and Edwin, H. W. C.: Indicators for evaluating environmental performance of the Hong Kong urban renewal projects, Facilities, 27, 515-530, 2009.
- Kienberger, S., Lang, S., and Zeil, P.: Spatial vulnerability units – expert-based spatial modelling of socio-economic vulnerability in the Salzach catchment, Austria, Nat. Hazards Earth Syst. Sci., 9, 767-778, 2009.
- King, D.: Uses and limitations of socioeconomic indicators of community vulnerability to natural hazards: Data and disasters in northern Australia, Nat. Hazards, 24, 147-156, 2001.
- McLaughlin, S., McKenna, J., and Cooper, J. A. G.: Socio-economic data in coastal vulnerability indices: constraints and opportunities, J. Coast. Res., 2002. 487-497, 2002.
- Meentemeyer, V.: Geographical perspectives of space, time, and scale., Landscape Ecology 3, 163-173, 1989.
- Myers, C. A., Slack, T., and Singelmann, J.: Social Vulnerability and Migration in the Wake of Disaster: The Case of Hurricanes Katrina and Rita, Population and Environment, 29, 271-291, 2008.
- Noy, I.: The macroeconomic consequences of disasters, Journal of Development Economics, 88, 221-231, 2009.
- OECD: Handbook on Constructing Composite Indicators: Methodology and User Guide, OECD Publishing, 2008.

- Oliver-Smith, A.: Theorizing Vulnerability in a Globalized World: A political Ecological Perspective In: Mapping Vulnerability: Disasters, Development and People, Bankoff, Frerk, and Hilhorst (Eds.), Earthscan, London, 2003.
- Openshaw, S.: The Modifiable Areal Unit Problem, Geo Books, Norwich, 1983.
- Pacione, M.: Urban geography: a global perspective, Routledge, London etc., 2005.
- Rashed, T. and Weeks, J.: Assessing vulnerability to earthquake hazards through spatial multicriteria analysis of urban areas, International Journal of Geographical Information Science, 17, 547-576, 2003.
- Rygel, L., O'sullivan, D., and Yarnal, B.: A Method for Constructing a Social Vulnerability Index: An Application to Hurricane Storm Surges in a Developed Country, Mitigation and Adaptation Strategies for Global Change, 11, 741-764, 2006.
- Schmidtlein, M. C., Deutsch, R. C., Piegorsch, W. W., and Cutter, S. L.: A Sensitivity Analysis of the Social Vulnerability Index, Risk Analysis, 28, 1099-1114, 2008.
- Shuang-Ye, W., Brent, Y., and Ann, F.: Vulnerability of coastal communities to sea-level rise: a case study of Cape May County, New Jersey, USA, Climate Research, 22, 255-270, 2002.
- Simpson, D. and Katirai, M.: Indicator Issues and Proposed Framework for a Disaster Preparedness Index (DPI), University of Louisville, Louisville, KY, USA, 2006.
- Sister, C., Wolch, J., and Wilson, J.: Got green? addressing environmental justice in park provision, GeoJournal $V 75, 2009. 229-248, 2009.
- Stow, D., Lopez, A., Lippitt, C., Hinton, S., and Weeks, J.: Object-based classification of residential land use within Accra, Ghana based on QuickBird satellite data, International Journal of Remote Sensing, 28, 5167-5173, 2007.
- Turvey, R.: Vulnerability Assessment of Developing Countries: The Case of Small-island Developing States, Development Policy Review, 25, 243-264, 2007.
- Warmer, K., Kuhlicke, C., Vries, D. d., Sakdapolrak, P., Wutich, A., Real, B., Briones, F., and Verjee, F.: Perspectives on Social Vulnerability, UNU-EHS, Bonn, Germany06/2007, 132 pp., 2007.
- Wolch, J., Wilson, J. P., and Fehrenbach, J.: Parks and Park Funding in Los Angeles: An Equity-Mapping Analysis, Urban Geography, 26, 4-35, 2005.

These references were incorporated into the manuscript, not only in the introduction but also in the discussion of results. Please see the texts as follows:

1 Introduction

Vulnerability is defined by the United Nations Office for Disaster Risk Reduction (UNDRR) as 'the characteristics and circumstances of a community, system, or asset that make it susceptible to the damaging effects of a hazard' (Aubrecht et al., 2013). In the past, vulnerability was considered a composite factor having only two dimensions: exposure to risk and susceptibility (Béné, 2009; Chambers, 1989). More recently, Birkmann (2013) considered three factors: exposure, susceptibility, and fragility and lack of resilience. The degree of vulnerability of a specific community is a human value judgement that highly influences management decisions (McLaughlin et al., 2002). In addition, the concept of social vulnerability (SV) to environmental hazards involves demographic and socio-economic factors that affect community resilience (Zebardast, 2013), and this is considered a hot topic in current disaster research (Shen et al., 2018). The social and economic dimensions are only two dimensions of vulnerability to multiple stressors and shocks. These shocks include disasters due to the fragility and susceptibility of human well-being damaged by disruption to individuals (physical and mental health) and collective social systems (e.g., education, services, health) and their characteristics (e.g., age, ethnicity, disabilities) (Birkmann et al., 2013). Social vulnerability refers to the inability of people, organisations, and societies to cope with negative impacts from different stressors to which they are exposed (Eidsvig et al., 2014; Kuhlicke et al., 2011; Myers et al., 2008; Qasim et al., 2018). Typically, this inability results from pre-existing conditions that reduce a society's ability to prepare and recover from disasters (Alcorn et al., 2013; Cutter and Finch, 2008; Eidsvig et al., 2014; Zebardast, 2013; Zhou et al., 2014). Social vulnerability additionally identifies sensitive populations that are less prepared to respond, cope with, and recover from a disaster (Zebardast, 2013) such as low-income populations, women, pregnant women, children below 5 years, elderly above 65 years (Zhou et al., 2014) and physically and or mentally challenged individuals (Contreras and Kienberger, 2012). Other vulnerable population groups are people with language, cultural and spatial barriers (Eidsvig et al., 2014) such as migrants (Yuan et al., 2019a), rural population, people without post-secondary education (Cutter et al., 2003; Eidsvig et al., 2014) and high-density population (Cutter et al., 2003; Eidsvig et al., 2014).

The concept of SV is complex and dynamic, changing through the time and over space, and therefore not easily captured by a single variable (Cutter and Finch, 2008; Zebardast, 2013). It represents the multidimensionality of disasters by focusing attention on the totality of relationships in a given social situation, which, in combination with environmental forces, such as geohazards, result in a disaster (Oliver-Smith, 2003). Social vulnerability attracts less attention by researchers because many challenges are implied in its quantification (Qasim et al., 2018). Power relationships that exclude certain individuals or groups from benefiting from disaster risk reduction (DRR) or post-disaster recovery efforts are examples of SV (Contreras et al., 2011). These power relationships manifest between individuals or socio-economic groups in the framework of institutions or culturally determined dialogues about stressors (Warmer et al., 2007).

The economic dimension of vulnerability is the predisposition for the loss of economic value from damage to physical assets (Birkmann et al., 2013) and/or business interruption (activities, services or delivery of products). The assessment of SV is orientated to cast light on the most susceptible groups of a population to be impacted by a disaster, in the spatial and temporal dimensions (Zhou et al., 2014). Another important aspect to consider is the relationship between social and economic dimensions because, according to Noy (2009), no evidence exists of a correlation between consequences of disasters, such as the number of fatalities or affected population, and GDP growth. Nevertheless, the same author indicates that the degree of damage due to a disaster will negatively influence GDP growth. Thus, Noy (2015) proposes to integrate the number of fatalities and injuries with financial damage due to a disaster using a model similar to the estimation of disability-adjusted life years (DALYs). His index accounts for the number of human years lost as a result of the damage. The spatial dimension of socio-economic vulnerability (SEV) recognises that people and groups of similar characteristics tend to occupy the same or similar areas, while the temporal dimension of SEV makes reference to people's degree of vulnerability that can change depending on age, life situation, and season (Wisner and Uitto, 2009). To include urban vulnerability assessment into a spatial plan requires strategic, technical, substantial, and procedural integration (Hizbaron et al., 2012). According to Ebert et al., (2009) a spatial indicator of SV is an SV indicator with a physical component. Housing structures and the built environment were previously included by Shuang-Ye, Brent, and Ann (2002) in a GIS-based study of SV. The link between transportation infrastructure and land use had been already studied by Clark et al. (1998). The physical conditions were considered indicative of the social ones by Rashed and Weeks (2003). Kienberger et al.,(2009) proposed a methodology for the spatial quantification of vulnerability and the identification of vulnerability units build upon the *geon* concept, which is a framework for the clustering of homogeneous spatial information. Khazai et al., (2013) developed a sector-specific vulnerability index (IVIs), which included transport dependency indicators made up by the spatial variables such as freight transport volume road and freight transport volume railway; this index also included the spatial variable of customer proximity as part of the indicator demand dependency.

In the context of disaster risk management, and mainly for exposure and impact assessment, the accuracy and reliability of input data are two of the most important factors (Aubrecht et al., 2013). Data constraints plays a key role in the results of the SEV assessment, with the number of variables changing the assessment, and the inclusion of more variables enhancing its precision and enabling the proper presentation of SV assessment (Gautam, 2017). Thus, the assessment of vulnerability must be based on indicators and proxy indexes (Qasim et al., 2018) that can guarantee objectivity and can provide quantitative metrics to compare different places (Cerchiello et al., 2018). Indicators and indexes are defined as single qualitative or indirect quantitative measures of a characteristic (Chen, 2016) or a real phenomenon (Fekete, 2009) resulting from systematically observed facts (OECD, 2008). Indicators transform complex data into manageable units of information for performance, change, and achievement assessment (Grace and Edwin, 2009). Indicators also summarise technical information into indexes, simplifying comprehension (Simpson and Katirai, 2006). The most important factor for indicator selection is the availability of data. The lack of data can lead to reliance on variables that may not be the most accurate indicators of vulnerability (Zhou et al., 2014). Vulnerability indicators are complex measures of a part of what constitutes a community. Scientific literature has identified groups of social and economic indicators, which combined with physical and land data, are useful for the vulnerability assessment of communities (King, 2001). The use of these indicators has primarily been applied to the assessment of adaptive capacity and vulnerability (Chen, 2016).

Indexes are built up with those indicators and later mapped to display the different categories of vulnerability in each administrative zone, limiting the spatial dimension to this stage. The construction of an index implies selection of indicators, indicator normalization and weighting, and aggregation into an index (OECD, 2008) that must collectively represent aspects of the society's ability to prepare for, deal with, and recover from a disaster (Eidsvig et al., 2014). The most sensitive step for constructing an index is the weighting of indicators. This can be undertaken either using participatory approaches such as the analytic hierarchy process (AHP), the budget allocation process, statistical assessment like the principal component analysis (PCA), or factor analysis (FA) (Eidsvig et al., 2014; OECD, 2008). Weighting individual indicators is a major challenge for constructing a composite indicator for vulnerability (Adger et al., 2004; Zebardast, 2013). The objectives of indicators weighting are first, to investigate any correlation among indicators to detect overlapping information and second, to select a suitable weighting and aggregation approach for the final index calculation. Different weightings show varied spatial vulnerability patterns (Papathoma-Kohle et al., 2019); however, independent of the method applied, after comparing 106 studies for index construction with respect to risk assessment, Beccari (2016) found that the most common approach used (41.5%) was the 'equal weights' method. Eventually, the accuracy of SV assessment lies on the accuracy of input data (Yuan et al., 2019a) and not on the weighting method. After being weighted, indicators can be aggregated using additive, multiplicative, or decision rule models (Eidsvig et al., 2014). The method of aggregation is one of the most pressing problems in developing composite vulnerability indices (Rygel et al., 2006).

Composite indicators have been commonly employed by researchers, planners, and disaster managers for vulnerability assessments (Yuan et al., 2019a). Cutter, Boruff and Shirley (2003) have constructed an index of SV called (SoVI®) for environmental hazards in the United States using a factor analytic approach computed in a summary score based on an additive model. In the framework of the Methods for the Improvement of Vulnerability Assessment in Europe (MOVE) project, variables were grouped into single (Vinchon et al., 2011) and composite indicators. In the case study area of Salzburg, an expert-based approach was chosen, and several experts were asked to allocate weights according to the contribution of each variable to the vulnerability of floods (Contreras and Kienberger, 2011). Other composite indicators useful for the vulnerability assessment are the Prevalent Vulnerability Index (Cardona, 2005), Environmental Sustainability Index (Esty et al., 2005), and Human Development Index (UNDP, 2010). All these indexes face challenges when assessing vulnerability indicators, such as: ranking socio-economic data on an interval scale, dealing with temporal aspects (day-night changes), choosing the most suitable data resolution to avoid the 'modifiable areas unit problem' (MAUP) (Openshaw, 1983), deciding how to allocate a meaningful value to socio-economic variables, and how these aspects together affect the vulnerability assessment of each case study areas (McLaughlin et al., 2002). The compilation of all of the SV indicators used through time was undertaken by Fatemi, Ardalan, Aguirre, Mansouri and Mohammadfam (2017); however, they neither included the spatial dimension in their systematic review nor focused exclusively on geohazard as in this research.

Quantitative measures to develop indicators can be spatially explicit and based on spatial variables, such as location, area, range, distance, direction, spatial geometries, and patterns (Unwin, 1996), spatial connectivity, mobility (Béné, 2009), isolation, diffusion, distribution, spatial association, spatial interaction, spatial evolution, spatial synthesis and scale of the affected area, and surroundings (Béné, 2009; Buzai and Villerías Alarcón, 2018; Contreras et al., 2013; Meentemeyer, 1989). The geographic patterns in vulnerability can increase due to spatial interactions; while additional patterns within these components may be related to the nature of vulnerability stemming from a specific hazard (Amram et al., 2011). The main aim of this research is to elucidate the state of the art in data sources, spatial variables, indicators, methods, indexes, and tools for the assessment of the SEV related to geohazards in urban environments. Geohazards can be internal such as earthquakes, tsunamis, and volcanic eruptions and external such as landslides, soil erosion, and land degradation. We particularly focus on these phenomena for two reasons: first, geohazards are the natural phenomena that have produced the highest quantity of losses in recent years in the urban environments in Chile, and, second, because geohazards are the phenomena addressed by the institutions involved in the present research.

The Indian Ocean tsunami in 2004, as a result of its large impact area, reignited the research community's interest in spatial vulnerability analyses, illuminating the problems faced by low-income population after disasters (Fekete, 2012). This approach was aligned with the Hyogo Framework for Action (UNISDR, 2007), and confirmed by Gautam (2017), who notes that after 2005 a focus on construction and mapping of the SV index intensified. Thus, the use of geographic information systems (GIS) to collect and process data related to hazards and vulnerability was found very suitable (Fekete, 2012). Major earthquakes in the same period as this systematic review (2010-2020), e.g. Chile (2010), New Zealand (2010 and 2011), Nepal (2015), Mexico (2017), Albania (2019), and Croatia (2020) demonstrate the vulnerability of urban areas to seismic damages (Armaş et al., 2017).

This research reviews case study areas, data sources, spatial variables, indicators, methods, indexes, and tools used in the spatial assessment of SEV vulnerability by different authors in the period between 2010 and 2020. This systematic review aims to evaluate the literature to identify patterns and trends, as well as research gaps, to recommend new research areas. This article aspires to guide scientists who want to perform any spatial assessment of SEV vulnerability. Socio-economic vulnerability is dynamic and changes across spatial and temporal scales, depending on demographic, geographic, economic, and cultural factors. Hence, no one-size-fits-all approach exists to measure and reduce SV (Zhou et al., 2014). This paper is divided into six sections. The introduction is the first section and includes a literature review. The second section, on methods, elaborates on the criteria for selecting the articles that comprise the systematic review and the format of the presentation of results. The third section focuses on the results. The fourth section includes discussion of the results supported by literature, and, the fifth section contains conclusions with recommendations proposed in the sixth section.

4 Discussion

For the purpose of the systematic review, we found that the Clarivate Analytics database more accurately identified the references for this systematic review, and it is more user-friendly, than other databases. The lack of articles that tackle external geohazards can be explained by the fact that we excluded from the search query words such as "climate change" OR "ecological" OR "drought", which are indirectly related to these phenomena. Nevertheless, considering that these geohazards usually takes place in rural, rather than urban environments, they are not relevant for this research.

The case study areas of the selected papers confirm the finding from Shen et al., (2018) relating to the USA, China, and Iran as major contributors to disaster research together with Italy, Indonesia, Germany, Turkey, England, India, and Spain in the topics of 'prediction model', 'social vulnerability' and 'landslide inventory map'. Nevertheless, the references that use Indonesia as a case study area are focused on earthquakes and volcanic eruptions, not necessarily on the tsunami hazard as was suggested by Shen et al., (2018).

The research concentrated on the local level uses primary data collected via field observations, questionnaire surveys, or focus groups with representative members of the community to assess vulnerability (Birkmann, 2006; Khazai et al., 2017; Sarkar and Vogt, 2015), while for global or regional scales, primary data is derived from satellite images, aerial Photograph, LULC, landslide susceptibility maps, orthophotos, or VGI. Secondary data is obtained from the population census, disaster databases, and population datasets. For applications on the regional, national, international, or worldwide scale, coarse-scale raster data on population patterns are appropriate, but for city or local scales, representation of higher spatial resolution is requested, such as fine-scale population grids which finally go to individual building level (Aubrecht et al., 2013). Census data usually presents national data at the municipal level. Census and land databases are highly demanded by planners and disaster managers. However, there are several problems associated with using large community databases, such as scale, data decay, relevance (King, 2001), and time-constrains. Current data can easily change with the building of a new road or new houses (McLaughlin et al., 2002), and in the case of nomadic and/or geographically isolated groups, these data sets are rarely available (Béné, 2009) but they are necessary. Censuses are usually updated on an average of ten years, depending on the country, and some of the data could be altered by political biases. The surveys require significant resources, and the thematic scope is usually very narrow. These disadvantages can explain the strong demand for population data, independent of administrative areas, making it sometimes necessary to extract data from raster representations or using dasymetric mapping (Aubrecht et al., 2013; Garcia et al., 2016; Yuan et al., 2019a). Currently, data in 3D can be also extracted from VGI, which is an alternative source of real-time information based on the concept of citizens as sensors (Cervone and Hultquist, 2018).

Satellite images are useful to collect data from global to local scales. Rapid mapping concepts are mainly applied in structural post-disaster damage assessment, relaying on earth observation data from different sensors, sometimes provided by the International Charter Space and Major Disasters (2020) (Aubrecht et al., 2013). Lidar data are a good option for the city scale. The use of satellite images as data sources in the spatial assessment of SEV has been increasing in the last ten years, which can be explained because they offer quick, updated, and reliable data, making the satellite images currently the most effective source. One of the issues with using maps, air photos, or orthophotos as a resource is that they are not frequently updated.

The spatial variables found through this systematic review are similar to the variables identified by Meentemeyer (1989), Béné, (2009) Contreras et al. (2013), Buzai and Villerías Alarcón (2018). Based on the concept of spatial indicator of SV formulated by Ebert et al., (2009), we consider the lack of basic services as a spatial variable of SEV because all these networks are distributed in a specific spatial area. The lack of life-supporting infrastructure and/or infrastructure necessary for the functioning of the society such as piped water, electricity networks, sewerage infrastructure, telecommunications and road networks hampers emergency management and therefore the recovery process (Eidsvig et al., 2014). Housing quality and tenancy conditions describes the vulnerability of the population to become homeless after a disaster (Toke et al., 2014). Housing type is an economic indicator of the economic status of individuals, communities, and nations. Thus, a house with low quality or precarious external walls located in a landslide-prone zone is usually associated with socially vulnerable communities having a negative influence on the quality of life. However, the typology of vulnerable houses depends also on the sort of landslide (Eidsvig et al., 2014). There are similar spatial variables used to produce an indicator of housing overcrowding (Ponce-Pacheco and Novelo-Casanova, 2018) such as households per housing unit (Zebardast, 2013) and Households with >1 family (Aksha et al., 2020). We argue that besides spatial variables, we must also consider spatial categories in which critical and the other urban facilities must be included. These facilities are not only providers of services but are also sources of employment (Contreras et al., 2017); therefore, their presence or absence, access to, distance, travel time (Toke et al., 2014), and/or barriers (Walker et al., 2014) to reaching them highly influence the degree of spatial SEV of a community. We also identify other spatial variables that are different to more traditional ones such as distance from faults (Hizbaron et al., 2012; Rezaei-Malek et al., 2019) and volcanoes (Kurnianto et al., 2019), land use (Alcorn et al., 2013), city blocks (Yuan et al., 2019a) and displacement (Muir et al., 2019) among others.

Based on the evidence found by this research, we agree with Zeng et al. (2012) that the most frequent spatial indicator in the assessment of SEV related to geohazards is population density, and it has the highest sensitivity coefficient (Yuan et al., 2019a). According to Kurnianto et al., (2019), high population density is the factor that contributes most to the high SV, and it is usually linked to high population growth, which increases the SEV given the rise in the exposure of population and business. The reason, according to Gu et al. (2018), is that population density reveals the human resources of a neighbourhood and the relief resources that could be required during a disaster. This is a key factor in large case study areas where different kinds of occupation can take place (urban, rural); therefore, important differences in population density are expected to be found. Disadvantaged population tends to live in denser neighbourhoods with more crowded parks and other recreational facilities (Sister et al., 2009; Toke et al., 2014; Wolch et al., 2005) and low levels of walkability (Bereitschaft, 2017b) that exacerbate their vulnerability making an evacuation difficult (Cutter et al., 2003) after an earthquake, tsunami, volcanic eruption, or landslide. It is also more difficult in such areas to find spaces to install temporary shelters near their households or areas for providing care after an emergency (Cutter et al., 2003). The density of the built environment is especially important in the case of seismic events (Toke et al., 2014). Innovative spatial indicators such as employed density, unemployed density, and literacy people density were proposed by Alizadeh et al. (2018). The importance of such fine-scale data and the temporal variations (daytime and night-time) for accurately estimating SV was highlighted by Yuan et al., (2019a), proposing the indicator: 'floating population'. The consideration of the spatial and temporal dimension in the estimation of population exposure is a fundamental aspect of accurate catastrophe loss modelling, a key element for the integration of risk analysis and emergency management (Aubrecht et al., 2010), and therefore for the reduction of the SEV (Alizadeh et al., 2018). Chen (2016) proposes more spatial indicators in the economic rather than the social dimension. Ley-García et al. (2015), global Moran's I and LISA enable the identification of dependence between attributes and localisations. As a result, these indicators are useful to determine whether the spatial distribution of elements influences the behaviour of a particular variable. The summary measure of autocorrelation in the territory is undertaken with global Moran's I, while the autocorrelation of the spatial units included in the territory is measured using LISA. Cutter and Finch (2008) also previously utilised global Moran's I and LISA to identify local variability and cluster similarity of low and SV. Besides the SoVI® and FA, Zhou et al. (2014) utilise exploratory spatial data analysis (ESDA) to identify the spatio-temporal patterns of SV based on the constructed SoVI® for each county in China. These authors used global and local Moran's I or LISA as ESDA to determine the spatial autocorrelation among counties and identify the similarity and/or dissimilarity in the clustering of SV.

Accessibility as spatial indicator is defined as the ability for contact and interaction with places of economic or social opportunities (Deichmann, 1997). Goodall (1987) notes that accessibility is the ease to reach a location from another location, and this concept is related again to the opportunities for contact, interaction, and attention (Aubrecht et al., 2013) in the case of, for example, hospitals and/or trauma centres, accessibility is reduced by distance (Hizbaron et al., 2012; Zeng et al., 2012). Besides the common spatial variables, indicators and indexes in 2D, there are also spatial indicators and indexes that include a 3D component, such as Walk Score®, neighbourhood walkability (Bereitschaft, 2017a, b), satisfaction with the neighbourhood (Barata et al., 2011), and residential condition (de la Torre and de Riccitelli, 2017) that could be applied to the spatial assessment of SEV. Authors such as Yuan et al

(2020) and Muir et al (2019) consider the spatial indicators of mobility and migration respectively in the framework of geohazards, being migration a topic mainly addressed by authors in the climate change community e.g. Nakayama et al.,(2019), Naugle et al.,(2019), Locke,(2009) and so forth.

This systematic review identified the versatility of ANN, which can be either used to extract monthly rainfall data (Aksha et al., 2020), for deriving social vulnerability maps (SVM) (Alizadeh et al., 2018) or to train the self-organized map (SOM) algorithm cluster method (Maharani et al., 2016). The use of dasymetric population mapping not limited to administrative boundaries, even going to block-level to increase the spatial resolution of the population exposure analysis (Garcia et al., 2016) and additionally by including the temporal dimension with its day-night variability, enables improving the accuracy of the spatial assessments of SEV (Yuan et al., 2019a). Factor analysis (FA) is used by Castro et al. (2015) to establish the level of SEV and by Zebardast (2013) to extract primary dimensions and variables of SEV. Alcorn (2013) applied MCE to assess economic vulnerability using four significant factors: population, infrastructure, land use, and economic production. SMCE is applied by Armaş et al., (2017) to integrate social, education, housing, and social dependence vulnerability dimensions and by Hizbaron (2012) to develop deterministic SV scenarios. Zebardast (2013) enters the variables of SEV into a network model in an analytic network process (ANP) to rank the importance of each variable to complete the F'ANP method. This method is focused on developing a composite social vulnerability index (SOVI). Binary logistic regression was the statistical method applied by Qasim et al. (2018) to identify the determinants of landslide risk perception, location being one of them. Walker et al., (2014) present a multi-criteria evaluation (MCE) model that incorporates access to healthcare facilities using GIS to identify and rank residential areas in Victoria, British Columbia. The integration of the concept of uncertainty into ANP using fuzzy numbers (F-ANP) is combined by Rezaei-Malek et al., (2019) with fuzzy DEMATEL (F-DEMATEL) to deal with the interdependency among a set of criteria and fuzzy PROMETHEE II (F- PROMETHEE II) to control the criteria weights, the complete method is denominated fuzzy ANP DEMATEL PROMETHEE II (F-ADP). Ordinal logistic regression (OLR) is used by Muir et al., (2019) to predict the mental health condition of people displaced by series of volcanic eruptions in Merapi, Indonesia, according to their migration status (displaced, moved home, in transition, and moved on), which implies a spatial component. Geological experience and logical analysis method were used by Chen (2016) to select indicators. Toke et al.,(2014) undertake an overlay analysis to identify the census block groups that intersect zones with an extreme ground shaking hazard.

Aksha et al., (2020) utilized the SoVI® to map the vulnerability levels in the study site with a multi-hazard map to produce a total risk map. Alcorn et al. (2013) used an improved version of the same index, but specifically adapted it to the variability in SEV in the case study area that was focused on census-designated places (CDPs) on a small scale. The population vulnerability indexing developed by Yuan et al., (2019a) considered most of the indicators available in the literature already identified by the SoVI®, but they adapted their index to the Chinese society, where according to the authors, race and ethnicity are not relevant indicators and rural-to-urban migrants are floating population with unequal access to public services and therefore a vulnerable population. Toké et al (2014), build upon the SoVI® to create their own SV indexes that incorporate the spatial dimension. According to the LA-SoVIC developed by Toket et al. (2014) SV is highly linked to the normalised difference vegetation index (NDVI) as a proxy for urban green space. Green areas are usually located in areas with lower SEV (Stow et al., 2007), and have also been recognised for their health benefits (Bedimo-Rung et al., 2005). Physical characteristics of green areas, such as attractive scenery, motivates people to stay and visit an area (Kurnianto et al., 2019), resulting in increased social control and reduced SEV.

It has been always difficult to quantify SV; hence, it is absent from post-disaster cost/loss estimation reports (Schmidtlein et al., 2008; Zhou et al., 2014). The use of spatial variables, indicators, and indexes will bridge the gap of integrating physical vulnerability and SV to achieve a holistic risk assessment. Davidson (1997) provides the first attempt to create an integrated risk assessment framework. Later, Carreño, Cardona, & Barbat, (2007) developed a risk index obtained by multiplying the physical risk index by an impact factor, which is, in fact, an aggravating coefficient consisting of socio-economic variables; nevertheless, in applying this method, the outcome will be similar to the assessment of physical vulnerability, without showing the contribution of SV to the assessment of integrated risk. Schmidtlein, Shafer, Berry and Cutter (2011) tested the link between SV and earthquake losses. The authors found that physical parameters related to hazard, such as distance from the epicentre and peak ground acceleration, were more significant in predicting impacts than SV. Nevertheless, the same authors established that SV is a significant predictor of earthquake losses when accounting for wealth (dollar losses per average income as the dependent variable). The previous finding reveals that those areas with higher levels of SV experience a greater relative impact than areas with lower degrees of SV.

Geospatial information systems are broadly utilised by several authors to collect and, process data, and map the SEV. GIS has been enabling researchers to have either large study regions, or equivalently, data sets at much finer spatial resolution (Unwin, 1996), for example, a comprehensive overview of the use of accessibility indicators in GIS was already provided by Deichmann (1997). Each author uses different versions of ArcGIS, which is the most widespread software used in GIS. The IDRISI software is utilised by Alizadeh et al. (2018) to generate a Social Vulnerability Map (SVM). Armaş et al., (2017) applied a pairwise comparative method in the AHP implemented in the SMCE module of the Integrated Land and Water Information System (Ilwis) software. GeoDa, an open-source software, focused on methods for spatial data, and has been used by authors who address the topic of spatial association (Gu et al., 2018; Ley-García et al., 2015). The aforementioned is an RS and GIS software, on which the robustness of the results from Armaş et al. (2017) was also tested, with a sensitivity analysis performed in the DEFINITE toolbox implemented in IlWIS. The MATLAB computation environment was used by Maharani et al. (2016) to develop the SOM toolbox. Sherly et al. (2015) also use MATLAB to perform multivariate data analyses, such as PCA and Data Envelopment Analysis (DEA). REDATAM used as a source of data by Castro et al. (2015), is an interactive hierarchical database that contains microdata and/or aggregate socio-economic information from any geographical division at a national level. This database combines data from the census, surveys and other sources, resulting in a very comprehensive and useful source of spatial and not-spatial variables for the SEV.

- Please improve the definition of your research question, and on this basis the criteria on how you reduced the >200 papers to 21. This is a critical point in your method, so this selection needs to be very well justified and transparent.

Thanks for this observation. Following your request, we rephrased our research question to: what is the state of the art in the spatial assessment of SEV to geohazards in urban environments? Based on the refined research question, we refined also our search query including new key words, which were already listed in Table 1.

The gross number of articles identified using the search query were 29, having two matching references in Clarivate analytics and Scopus/Elsevier: Kurnianto et al., (2019) and Eidsvig (2014). Thus, eventually, we identified 27 references. Despite the precise search query, 11 references were discarded. The detailed reasons to rule these references out is explained in Table 2, but this is only for the information of the editor, a summarized version of the reasons explained in Table 2 will be in the final version of the manuscript.

	REFERENCE	YEAR	REASONS TO BE DISCARDED
1	Papathoma-Kohle, M., Cristofari, G., Wenk, M., & Fuchs, S.	2019	It presents a couple of indexes (PTVA-3 and PTVA-4) made up of variables in the physical dimension, rather than socio-economic, for the assessment of the vulnerability of buildings to tsunamis in Apulia (Italy).
2	Yuan, H. H., Gao, X. L., & Qi, W.	2019	Another reference from the same authors was already selected for the review: Yuan, H. H., Gao, X. L., & Qi, W.

	REFERENCE	YEAR	REASONS TO BE DISCARDED
			(2019). Fine-Scale Spatiotemporal Analysis of Population Vulnerability to Earthquake Disasters: Theoretical Models and Application to Cities. Sustainability, 11(7), 19. doi:10.3390/su11072149
3	Zhang, N., & Huang, H.	2018	This paper provides a Gaussian blur-based method to calculate the average severity of disasters, rather than focusing on methods for the spatial assessment of SEV.
4	Shen, S., Cheng, C. X., Yang, J., & Yang, S. L.	2018	This reference analyses the trends and hot topics in disaster research in recent years. 'social vulnerability' is identified as one of the hot topics, but the authors do not go deep into this topic in the paper.
5	Goncalves, M., & Vizintim, M. F. B.	2017	This article is written in Portuguese and none of the authors are proficient in this language.
6	Karagiorgos, K., Heiser, M., Thaler, T., Hubl, J., & Fuchs, S.	2016	This paper addresses the topic of flash floods, which is a hazard not included in the search query.
7	Postiglione, I., Masi, A., Mucciarelli, M., Lizza, C., Camassi, R., Bernabei, V., . . . Peruzza, L.	2016	This reference elaborates on an Italian communication campaign oriented to prevent or at least reduce the risk associated with earthquakes with the aim to promote a culture of seismic risk prevention starting with volunteers to serve later as multipliers. Prevention campaigns due to seismic hazard are out of the scope of our manuscript.
8	Alcántara-Ayala, I., & Oliver-Smith, A.	2014	This article presents the activities undertaken by the ICL Latin-American network (ICLLAN) related to capacity building to reduce risk due to landslides through forensic investigations. It deals with one of the geohazards considered in this paper, but not the spatial assessment of SEV.
9	Khazai, B., Daniell, J. E., Düzgün, Ş., Kunz-Plapp, T., & Wenzel, F.	2014	This reference was discarded for two reasons. First, it is focused on modelling shelter needs and health impacts caused by earthquakes rather than the spatial assessment of SEV. Second, it is a book chapter, while the systematic review focuses on articles.
10	Vilches, O. R., Carrillo, K. S., Reyes, C. M., & Castillo, E. J.	2014	This paper aims to evaluate the socio-environmental effects of the 27/10/2010 tsunami in Chile considering the SEV, the safety perception, and the environmental problems, in highly vulnerable rural towns, that depend on the extraction of resources from the sea. Although this is a very interesting topic is neither in the scope of the review nor does it make use of any spatial variable, indicator, or index that could be useful for the present review.

	REFERENCE	YEAR	REASONS TO BE DISCARDED
11	Jaque Castillo, E., Contreras, A., Ríos, R., & Quezada Flory, J.	2013	Although this reference assesses the socio-economic. educational and physical vulnerability due to tsunami in the Town of Tirua (Chile), it does not make use of any spatial, variable, indicator or index useful for the current research.

Table 2. References discarded for the systematic review.

The summarized version of the reasons to discard the 11 references, although they were identified through the search query, is described in the manuscript as follows:

'(…) Despite the precise search query, 11 references were discarded due to reasons explained as follows. In chronological order, the first reference discarded was Papathoma-Kohle et al., (2019) because they use variables in the physical dimension, rather than socio-economic one. Two references from Yuan et al., (2019a, b) were identified by the search query as using the same method for the spatial assessment of SEV; so, we decided to select only one of them. Zhang and Huang (2018) address the topic of SV but not its spatial assessment, while Shen et al. (2018) focused on calculating the impact of disasters, rather than estimating SEV. The paper written by Goncalves, M., & Vizintim, M. F. B. (2017) was written in Portuguese, which none of the authors is proficient. Postiglione et al., (2016) promote a culture of seismic risk prevention, rather than to estimate SEV due to earthquakes. Alcántara-Ayala and Oliver-Smith (2014) present the activities undertaken by the ICL Latin -American network (ICL LAB) related to capacity building to reduce risk due to landslides, with no specific emphasis on SEV. Khazai et al., (2014), in their book chapter, concentrate on modelling shelter needs and health impacts caused by earthquakes. Vilches et al. (2014) evaluate the socio-environmental effects of the 27/10/2010 tsunami in Chile, considering the SEV among other aspects, but they do not make use of any spatial variable, indicator, or index, which is similar to the vulnerability assessment relating to a tsunami in the Town of Tirua (Chile) undertaken by Jaque Castillo et al.,(2013) (…)'.

- The result of your paper analysis should be also improved, and your conclusions need to be underpinned more closely with your results.

Thank you very much for this observation. The result section was improved and our conclusions this time are totally supported by our findings. Please see the text of both sections below:

3 Results

The gross number of articles identified using the search query were 29, having two matching references in Clarivate Analytics and Scopus/Elsevier: Kurnianto et al., (2019) and Eidsvig (2014). Thus, eventually, we identified 27 references. Despite the precise search query, 11 references were discarded due to reasons explained as follows. In chronological order, the first reference discarded was Papathoma-Kohle et al., (2019) because they use variables in the physical dimension, rather than socio-economic one. Two references from Yuan et al., (2019a, b) were identified by the search query as using the same method for the spatial assessment of SEV; so, we decided to select only one of them. Zhang and Huang (2018) address the topic of SV but not its spatial assessment, while Shen et al. (2018) focused on calculating the impact of disasters, rather than estimating SEV. The paper written by Goncalves, M., & Vizintim, M. F. B. (2017) was written in Portuguese, which none of the authors is proficient. Postiglione et al., (2016) promote a culture of seismic risk prevention, rather than to estimate SEV due to earthquakes. Alcántara-Ayala and Oliver-Smith (2014) present the activities undertaken by the ICL

Latin -American network (ICL LAB) related to capacity building to reduce risk due to landslides, with no specific emphasis on SEV. Khazai et al., (2014), in their book chapter, concentrate on modelling shelter needs and health impacts caused by earthquakes. Vilches et al. (2014) evaluate the socio-environmental effects of the 27/10/2010 tsunami in Chile, considering the SEV among other aspects, but they do not make use of any spatial variable, indicator, or index, which is similar to the vulnerability assessment relating to a tsunami in the Town of Tirua (Chile) undertaken by Jaque Castillo et al.,(2013). Five references from the previous search query carried out in 2018, and not identified in the refined search query, were included in the list given their relevance due to the geohazards and spatial variables, indicators, and indexes that they address. The 23 references finally reviewed are listed in Table 2.

AUTHOR	YEAR	RESEARCH OBJECTIVE	HAZARD	COUNTRY
Aksha, S. K., Resler, L. M., Juran, L., & Carstensen, L. W.	2020	To introduce a model for spatial multi-hazards risk assessment applied to Dharan, Nepal.	Earthquakes, floods and landslides	Nepal
Kurnianto, F. A., Ikhsan, F. A., Apriyanto, B., & Nurdin, E. A. (2019)	2019	To assess the level of vulnerability for an earthquake disaster in Lembang district, an area in West Java that includes the Bandung basin	Earthquakes	Indonesia
Muir, J. A., Cope, M. R., Angeningsih, L. R., Jackson, J. E., & Brown, R. B.	2019	To explore whether return migration, compared to other migration options, results in superior improvements to mental health in the context of disasters.	Volcanic eruptions	Indonesia
Rezaei-Malek, M., Torabi, S. A., & Tavakkoli-Moghaddam, R.	2019	To prioritize disaster-prone areas which are known as potential demand points (PDPs) given their vulnerability under large-scale earthquakes	Earthquakes	Iran
Yuan, H. H., Gao, X. L., & Qi, W. (2019)	2019	To provide high spatial-temporal resolution information on vulnerable populations and population vulnerability using dasymetric population mapping with vulnerability index	Earthquakes	China
Alizadeh, M., Alizadeh, E., Kotenaee, S. A., Shahabi, H., Pour, A. B., Panahi, M., . . . Saro, L.	2018	To apply an artificial neural network (ANN) and geographic information system (GIS) for estimating the social vulnerability to earthquakes in the Tabriz city, Iran.	Earthquakes	Iran
Qasim, S., Qasim, M., Shrestha, R. P., & Khan, A. N.	2018	To define the socio-economic determinants of landslide risk perception in Murree hills of Pakistan.	Landslides	Pakistan
Ponce-Pacheco, A. B., & Novelo-Casanova, D. A.	2018	To estimate the levels of vulnerability and risk to floods, earthquakes and subsidence of Valle de Chalco Solidaridad (VCS) in Mexico	Earthquakes, floods and subsidence	Mexico
Armaş, I., Toma-Danila, D., Ionescu, R., & Gavriş, A.	2017	To develop an overall vulnerability index to seismic hazard based on a spatial approach applied to Bucharest, Romania.	Earthquakes	Romania
Gautam, D.	2017	To investigates social vulnerability to natural hazards in Nepal at district level.	Droughts, earthquakes, epidemics floods and landslides,	Nepal
Chen, Y.	2016	To develop a set of valid and reliable indicators to evaluate the regional	Landslides	China

AUTHOR	YEAR	RESEARCH OBJECTIVE	HAZARD	COUNTRY
		land subsidence disaster vulnerability in the Xixi-Chengnan area, in China.		
Garcia, R. A. C., Oliveira, S. C., & Zezere, J. L.	2016	To apply dasymetric cartography to improving population spatial resolution and to assess the potentially exposed population over large areas to deep rotational landslides and compare the results with those obtained with basic census units as the data source	Landslides	Portugal
Maharani, Y. N., Lee, S., & Ki, S. J.	2016	To propose the use of Self-Organizing Maps (SOM) approach to conducting the social vulnerability assessment around the Merapi volcano.	Volcanic eruptions	Indonesia
Castro, C. P., Ibarra, I., Lukas, M., Ortiz, J., & Sarmiento, J. P.	2015	To assess the social vulnerability of informal settlements in Iquique and Puerto Montt in Chile	Earthquakes, floods, landslides and Tsunami	Chile
Ley-García, J., Denegri de Dios, F. M., & Ortega Villa, L. M.	2015	The aim is to identify visibility, invisibility and amplification of hazardscape perception in the city of Mexicali, Baja California, Mexico.	Earthquake Landslide Tsunami Volcano Cyclone Thunderstorm Heavy rainfall Flood hail Snow-freeze Strong wind Drought Cold wave Heat wave	Mexico
Eidsvig, U. M. K., McLean, A., Vangelsten, B. V., Kalsnes, B., Ciurean, R. L., Argyroudis, S., . . . Kaiser, G.	2014	To propose a methodology to estimate socioeconomic vulnerability to landslides at the local to regional scale using an indicator-based model	Landslides	Andorra, France, Greece, Norway, and Romania
Toké, N. A., Boone, C. G., & Arrowsmith, J. R.	2014	To construct a relative social vulnerability index classification for Los Angeles to examine the social condition within regions of significant seismic hazard, including areas regulated as Alquist-Priolo (AP) Act earthquake fault zones.	Earthquakes landslides and wildfires	USA
Walker, B. B., Taylor-Noonan, C., Tabbernor, A., McKinnon, T. B., Bal, H., Bradley, D., . . . Clague, J. J.	2014	To model geophysical processes and identification of socio-economically disadvantaged populations in Victoria, British Columbia.	Earthquakes	Canada
Alcorn, R., Panter, K. S., & Gorsevski, P. V.	2013	To evaluate the spatial impact of a possible future eruption using a GIS-based volcanic hazard tool and to assess the social and economic vulnerabilities of the area at risk.	Volcanic eruption	USA
Aubrecht, C., Özceylan, D., Steinnocher, K., & Freire, S.	2013	To review available multi-level geospatial information and modelling approaches from local to global scales, that could serve	Tsunami, floods	Austria Portugal Turkey USA

AUTHOR	YEAR	RESEARCH OBJECTIVE	HAZARD	COUNTRY
		practitioners and researchers in disaster-related zones		
Zebardast, E.	2013	To develop a model that combines hybrid factor analysis and analytic network process (F'ANP) for constructing a composite social vulnerability index (SOVI)	Earthquakes	Iran
Hizbaron, D. R., Baiquni, M., Sartohadi, J., & Rijanta, R.	2012	To assess urban vulnerability due to seismic hazard using a risk based spatial plan	Earthquakes	Indonesia
Zeng, J., Zhu, Z. Y., Zhang, J. L., Ouyang, T. P., Qiu, S. F., Zou, Y., & Zeng, T.	2012	To introduce a new method to assess social vulnerability for county-scale regions using population density, based on land use.	Landslides	China

Table 2. Articles identified and selected by the systematic review.

The most recurrent geohazards addressed among the selected papers are earthquakes, followed by landslides, volcanic eruptions, tsunami, and subsidence, detailed information about the number of literature references that tackle each hazard is depicted in Figure 2. None of the references deals with soil erosion, nor land degradation. Case study areas selected from this set of papers are frequently located in Indonesia, China, Iran, and the USA, detailed information about the number of literature references that has case study areas on these countries can be appreciated in Figure 3. From the set of selected papers, the most common sources of data are the population census, followed by satellite images, field observations, disaster databases, surveys, aerial photographs, and land use and land cover (LULC) maps. Other authors used landslide susceptibility maps, orthophotos, and volunteered geographic information (VGI). The complete set of data sources identified in this systematic review are listed in Table 3.

DATA SOURCES		AUTHORS
Census data	Nepal census	Aksha, S. K., Resler, L. M., Juran, L., & Carstensen, L. W. (2020)
		Ponce-Pacheco, A. B., & Novelo-Casanova, D. A. (2018)
	City office of Dharan	Aksha, S. K., Resler, L. M., Juran, L., & Carstensen, L. W. (2020)
	National Institute of Statistics and Geography	Ponce-Pacheco, A. B., & Novelo-Casanova, D. A. (2018)
	Municipal Government of Valle de Chalco Solidaridad	Ponce-Pacheco, A. B., & Novelo-Casanova, D. A. (2018)
	Secretariat of Social Development of Mexico	Ponce-Pacheco, A. B., & Novelo-Casanova, D. A. (2018)
	CBS 2011 Census	Gautam, D. (2017)
	Xishan and Huishan Statistical Yearbook 2008	Chen, Y. (2016)
	Population and Housing Census 2010	Lin, W.-Y., & Hung, C.-T. (2016)
	National Census 2011	Garcia, R. A. C., Oliveira, S. C., & Zezere, J. L. (2016)
	Statistics of Sleman Regency https://slemankab.bps.go.id/	Maharani, Y. N., Lee, S., & Ki, S. J. (2016)

	DATA SOURCES	AUTHORS
	National census of population and VI of housing	Castro, C. P., Ibarra, I., Lukas, M., Ortiz, J., & Sarmiento, J. P. (2015).
	2000 U.S. Census Bureau	Toké, N. A., Boone, C. G., & Arrowsmith, J. R. (2014)
	Statistical Office of Baden-Wuerttemberg	Khazai, B., Merz, M., Schulz, C., & Borst, D. (2013)
	Regional Planning Board	Hizbaron, D. R., Baiquni, M., Sartohadi, J., & Rijanta, R. (2012)
	Statistical Bureau	Hizbaron, D. R., Baiquni, M., Sartohadi, J., & Rijanta, R. (2012)
	Armaş, I., Toma-Danila, D., Ionescu, R., & Gavriş, A. (2017)	
	Garcia, R. A. C., Oliveira, S. C., & Zezere, J. L. (2016)	
	Walker, B. B., Taylor-Noonan, C., Tabbernor, A., McKinnon, T. B., Bal, H., Bradley, D., . . . Clague, J. J. (2014)	
Satellite images	WorldView-3	Aksha, S. K., Resler, L. M., Juran, L., & Carstensen, L. W. (2020)
	ASTER-DEM	Aksha, S. K., Resler, L. M., Juran, L., & Carstensen, L. W. (2020)
	PERSIANN-CDR	Aksha, S. K., Resler, L. M., Juran, L., & Carstensen, L. W. (2020)
	Google Earth satelllite images	Castro, C. P., Ibarra, I., Lukas, M., Ortiz, J., & Sarmiento, J. P. (2015)
	GDEM-ASTER	Castro, C. P., Ibarra, I., Lukas, M., Ortiz, J., & Sarmiento, J. P. (2015)
	LANDSAT	Toké, N. A., Boone, C. G., & Arrowsmith, J. R. (2014)
	LANDSAT^{TM}	Aubrecht, C., Özceylan, D., Steinnocher, K., & Freire, S. (2013)
	SPOT	Zeng, J., Zhu, Z. Y., Zhang, J. L., Ouyang, T. P., Qiu, S. F., Zou, Y., & Zeng, T. (2012)
Satellite images	IKONOS	Aubrecht, C., Özceylan, D., Steinnocher, K., & Freire, S. (2013)
	NDVI	Aubrecht, C., Özceylan, D., Steinnocher, K., & Freire, S. (2013)
Field Observations	Alizadeh, M., Alizadeh, E., Kotenaee, S. A., Shahabi, H., Pour, A. B., Panahi, M., . . . Saro, L. (2018)	
	Ponce-Pacheco, A. B., & Novelo-Casanova, D. A. (2018)	
	Garcia, R. A. C., Oliveira, S. C., & Zezere, J. L. (2016)	
	Castro, C. P., Ibarra, I., Lukas, M., Ortiz, J., & Sarmiento, J. P. (2015)	
	Hizbaron, D. R., Baiquni, M., Sartohadi, J., & Rijanta, R. (2012)	
Disaster Databases	Indonesian Disaster Data Information (DIBI) http://dibi.bnpb.go.id/dibi/	Maharani, Y. N., Lee, S., & Ki, S. J. (2016)
	Risk Atlas of the Municipality of Mexicali 2011	Ley-García, J., Denegri de Dios, F. M., & Ortega Villa, L. M. (2015)

DATA SOURCES		AUTHORS
	Desinventar Data Base	Ponce-Pacheco, A. B., & Novelo-Casanova, D. A. (2018)
Surveys	Muir, J. A., Cope, M. R., Angeningsih, L. R., Jackson, J. E., & Brown, R. B. (2019)	
	Ponce-Pacheco, A. B., & Novelo-Casanova, D. A. (2018)	
	Qasim, S., Qasim, M., Shrestha, R. P., & Khan, A. N. (2018).	
Aerial Photograph	Castro, C. P., Ibarra, I., Lukas, M., Ortiz, J., & Sarmiento, J. P. (2015)	
	Toké, N. A., Boone, C. G., & Arrowsmith, J. R. (2014)	
LULC maps	CORINE	Aubrecht, C., Özceylan, D., Steinnocher, K., & Freire, S. (2013)
	HR Soil sealing layer	Aubrecht, C., Özceylan, D., Steinnocher, K., & Freire, S. (2013)
Population datasets	GPW/GPWv4	Aubrecht, C., Özceylan, D., Steinnocher, K., & Freire, S. (2013)
	GRUMP	Aubrecht, C., Özceylan, D., Steinnocher, K., & Freire, S. (2013)
Landslide susceptibility map (pixel terrain unit)	Garcia, R. A. C., Oliveira, S. C., & Zezere, J. L. (2016)	
Orthophoto	Armaş, I., Toma-Danila, D., Ionescu, R., & Gavriş, A. (2017)	
VGI	Aubrecht, C., Özceylan, D., Steinnocher, K., & Freire, S. (2013)	

Table 3. Data sources for the spatial assessment of socio-economic vulnerability (SEV).

The most common spatial variables used for the spatial assessment of SEV between 2010 and 2020 are households without basic services (piped water connection, electricity, sewerage infrastructure, cell phone, or landline), location, critical facilities (fire stations, medical emergency services, medical facilities, and hospitals), distance from faults/causative faults, precarious housing (low quality and/or precarious external walls, roofing, and floors), the total area of occupied space in the residences, and the presence of schools. The complete set of spatial variables identified in this systematic review are listed in Table 4.

SPATIAL VARIABLES	AUTHORS
Households without piped water connection, electricity, sewerage infrastructure, cell phone or landline	Aksha, S. K., Resler, L. M., Juran, L., & Carstensen, L. W. (2020)
	Ponce-Pacheco, A. B., & Novelo-Casanova, D. A. (2018)
	Gautam, D. (2017)
	Castro, C. P., Ibarra, I., Lukas, M., Ortiz, J., & Sarmiento, J. P. (2015)
	Zebardast, E. (2013)
Location	Kurnianto, F. A., Ikhsan, F. A., Apriyanto, B., & Nurdin, E. A. (2019)
	Muir, J. A., Cope, M. R., Angeningsih, L. R., Jackson, J. E., & Brown, R. B. (2019)
	Qasim, S., Qasim, M., Shrestha, R. P., & Khan, A. N. (2018)
	Castro, C. P., Ibarra, I., Lukas, M., Ortiz, J., & Sarmiento, J. P. (2015)
	Rezaei-Malek, M., Torabi, S. A., & Tavakkoli-Moghaddam, R. (2019)

SPATIAL VARIABLES	AUTHORS
Critical facilities (fire stations, hospitals, health services, medical emergency services, medical facilities, etc.)	Ponce-Pacheco, A. B., & Novelo-Casanova, D. A. (2018)
	Eidsvig, U. M. K., McLean, A., Vangelsten, B. V., Kalsnes, B., Ciurean, R. L., Argyroudis, S., . . . Kaiser, G. (2014)
	Alcorn, R., Panter, K. S., & Gorsevski, P. V. (2013)
	Zeng, J., Zhu, Z. Y., Zhang, J. L., Ouyang, T. P., Qiu, S. F., Zou, Y., & Zeng, T. (2012)
Distance from faults/ causative faults	Rezaei-Malek, M., Torabi, S. A., & Tavakkoli-Moghaddam, R. (2019)
	Hizbaron, D. R., Baiquni, M., Sartohadi, J., & Rijanta, R. (2012)
Household with low quality and/or precarious external walls, roofing and floors	Aksha, S. K., Resler, L. M., Juran, L., & Carstensen, L. W. (2020)
	Castro, C. P., Ibarra, I., Lukas, M., Ortiz, J., & Sarmiento, J. P. (2015)
Total area of occupied space in the residences	Armaş, I., Toma-Danila, D., Ionescu, R., & Gavriş, A. (2017)
	Zeng, J., Zhu, Z. Y., Zhang, J. L., Ouyang, T. P., Qiu, S. F., Zou, Y., & Zeng, T. (2012)
Schools	Alcorn, R., Panter, K. S., & Gorsevski, P. V. (2013)
	Zeng, J., Zhu, Z. Y., Zhang, J. L., Ouyang, T. P., Qiu, S. F., Zou, Y., & Zeng, T. (2012)
Families occupying rented houses	Aksha, S. K., Resler, L. M., Juran, L., & Carstensen, L. W. (2020)
Households per housing unit	Zebardast, E. (2013)
Households with >1 family	Aksha, S. K., Resler, L. M., Juran, L., & Carstensen, L. W. (2020)
City blocks	Yuan, H. H., Gao, X. L., & Qi, W. (2019)
Displaced, moved home, in transition, moved on	(Muir et al., 2019), J. A., Cope, M. R., Angeningsih, L. R., Jackson, J. E., & Brown, R. B. (2019)
Distance to volcanoes	Kurnianto, F. A., Ikhsan, F. A., Apriyanto, B., & Nurdin, E. A. (2019)
Availability of evacuation roads	Ponce-Pacheco, A. B., & Novelo-Casanova, D. A. (2018)
Housing occupation type/tenancy condition	Castro, C. P., Ibarra, I., Lukas, M., Ortiz, J., & Sarmiento, J. P. (2015)
Average household size	Toke, N. A., Boone, C. G., & Arrowsmith, J. R. (2014)
Housing type	Eidsvig, U. M. K., McLean, A., Vangelsten, B. V., Kalsnes, B., Ciurean, R. L., Argyroudis, S., . . . Kaiser, G. (2014)
Percentage of households with public assistance	Toke, N. A., Boone, C. G., & Arrowsmith, J. R. (2014)
Percent of workers with a long commute	Toke, N. A., Boone, C. G., & Arrowsmith, J. R. (2014)
Travel barriers to the trauma centres	Walker, B. B., Taylor-Noonan, C., Tabbernor, A., McKinnon, T. B., Bal, H., Bradley, D., . . . Clague, J. J. (2014)
Travel distance to trauma centres	Walker, B. B., Taylor-Noonan, C., Tabbernor, A., McKinnon, T. B., Bal, H., Bradley, D., . . . Clague, J. J. (2014)
Travel time to trauma centres	Walker, B. B., Taylor-Noonan, C., Tabbernor, A., McKinnon, T. B., Bal, H., Bradley, D., . . . Clague, J. J. (2014)
Walking time to trauma centres	Walker, B. B., Taylor-Noonan, C., Tabbernor, A., McKinnon, T. B., Bal, H., Bradley, D., . . . Clague, J. J. (2014)
Land use	Alcorn, R., Panter, K. S., & Gorsevski, P. V. (2013)

SPATIAL VARIABLES	AUTHORS
Housing with bathroom	Zebardast, E. (2013)
Housing with kitchen	Zebardast, E. (2013)
Migration status	Muir, J. A., Cope, M. R., Angeningsih, L. R., Jackson, J. E., & Brown, R. B. (2019)
Road type	Alcorn, R., Panter, K. S., & Gorsevski, P. V. (2013)
Spatial distribution of cell phone subscribers	Aubrecht, C., Özceylan, D., Steinnocher, K., & Freire, S. (2013)
Distance to hospital	Zeng, J., Zhu, Z. Y., Zhang, J. L., Ouyang, T. P., Qiu, S. F., Zou, Y., & Zeng, T. (2012)
Distance to road network	Hizbaron, D. R., Baiquni, M., Sartohadi, J., & Rijanta, R. (2012)
Distance to trauma centres	Walker, B. B., Taylor-Noonan, C., Tabbernor, A., McKinnon, T. B., Bal, H., Bradley, D., . . . Clague, J. J. (2014)
Distribution of urban greenspace	Toké, N. A., Boone, C. G., & Arrowsmith, J. R. (2014)
Industry land, Office land and commercial. residential land and park space	Zeng, J., Zhu, Z. Y., Zhang, J. L., Ouyang, T. P., Qiu, S. F., Zou, Y., & Zeng, T. (2012)
Population dependent on the land for the primary source of income	Eidsvig, U. M. K., McLean, A., Vangelsten, B. V., Kalsnes, B., Ciurean, R. L., Argyroudis, S., . . . Kaiser, G. (2014).
Road network	Zeng, J., Zhu, Z. Y., Zhang, J. L., Ouyang, T. P., Qiu, S. F., Zou, Y., & Zeng, T. (2012)

Table 4. Spatial variables for socio-economic vulnerability (SEV) assessments.

Population density, housing density, hospital beds per 1,000 people, and living space per person are the most frequent spatial indicators of SEV. Global Moran's I and local indicators of spatial association (LISA), which are traditional indicators in the spatial assessment, were also identified in this systematic research. We also found indicators such the access to environmental amenities and medical facilities, basic census units (BCU) target zones, and population, employed/unemployed density, floating population, and literate people density among others. The complete set of spatial indicators identified in this systematic review are listed in Table 5.

SPATIAL INDICATORS	AUTHORS
Population density (women/men density)	Alizadeh, M., Alizadeh, E., Kotenaee, S. A., Shahabi, H., Pour, A. B., Panahi, M., . . . Saro, L. (2018)
	Kurnianto, F. A., Ikhsan, F. A., Apriyanto, B., & Nurdin, E. A. (2019)
	Yuan, H. H., Gao, X. L., & Qi, W. (2019)
	Alizadeh, M., Alizadeh, E., Kotenaee, S. A., Shahabi, H., Pour, A. B., Panahi, M., . . . Saro, L. (2018)
	Armaş, I., Toma-Danila, D., Ionescu, R., & Gavriş, A. (2017)
	Chen, Y. (2016)
	Maharani, Y. N., Lee, S., & Ki, S. J. (2016)
	Eidsvig, U. M. K., McLean, A., Vangelsten, B. V., Kalsnes, B., Ciurean, R. L., Argyroudis, S., . . . Kaiser, G. (2014)
	Toké, N. A., Boone, C. G., & Arrowsmith, J. R. (2014)
	Hizbaron, D. R., Baiquni, M., Sartohadi, J., & Rijanta, R. (2012)
	Zeng, J., Zhu, Z. Y., Zhang, J. L., Ouyang, T. P., Qiu, S. F., Zou, Y., & Zeng, T. (2012)

SPATIAL INDICATORS	AUTHORS
Housing density	Alizadeh, M., Alizadeh, E., Kotenaee, S. A., Shahabi, H., Pour, A. B., Panahi, M., . . . Saro, L. (2018)
	Armaş, I., Toma-Danila, D., Ionescu, R., & Gavriş, A. (2017)
	Toké, N. A., Boone, C. G., & Arrowsmith, J. R. (2014)
Hospital beds per 1,000 people	Eidsvig, U. M. K., McLean, A., Vangelsten, B. V., Kalsnes, B., Ciurean, R. L., Argyroudis, S., . . . Kaiser, G. (2014)
	Zebardast, E. (2013)
Living space pp	Armaş, I., Toma-Danila, D., Ionescu, R., & Gavriş, A. (2017)
	Zebardast, E. (2013)
Degree of population aglomeration	Yuan, H. H., Gao, X. L., & Qi, W. (2019)
Floating population	Yuan, H. H., Gao, X. L., & Qi, W. (2019)
Mobility	Yuan, H. H., Gao, X. L., & Qi, W. (2019)
Spatial distribution	Yuan, H. H., Gao, X. L., & Qi, W. (2019)
Employed/ Unemployed density	Alizadeh, M., Alizadeh, E., Kotenaee, S. A., Shahabi, H., Pour, A. B., Panahi, M., . . . Saro, L. (2018).
Household overcrowding	Ponce-Pacheco, A. B., & Novelo-Casanova, D. A. (2018)
Literate people density	Alizadeh, M., Alizadeh, E., Kotenaee, S. A., Shahabi, H., Pour, A. B., Panahi, M., . . . Saro, L. (2018)
BCU target zones	Garcia, R. A. C., Oliveira, S. C., & Zezere, J. L. (2016)
BCU population	Garcia, R. A. C., Oliveira, S. C., & Zezere, J. L. (2016)
Density of agricultural/industrial production	Chen, Y. (2016)
Farming density	Chen, Y. (2016)
GDP density	Chen, Y. (2016)
Investment density of fixed assets	Chen, Y. (2016)
Global Moran's I	Ley-García, J., Denegri de Dios, F. M., & Ortega Villa, L. M. (2015)
LISA	Ley-García, J., Denegri de Dios, F. M., & Ortega Villa, L. M. (2015)
Access to environmental amenities (Park space, open spaces and walkable neighborhoods)	Toké, N. A., Boone, C. G., & Arrowsmith, J. R. (2014)
Access to medical facilities	Walker, B. B., Taylor-Noonan, C., Tabbernor, A., McKinnon, T. B., Bal, H., Bradley, D., . . . Clague, J. J. (2014)
Infrastructure dependance	Toke, N. A., Boone, C. G., & Arrowsmith, J. R. (2014)
Walkability	Toké, N. A., Boone, C. G., & Arrowsmith, J. R. (2014)

Table 5. Spatial indicators for socio-economic vulnerability (SEV) assessments.

Results extracted from the literature indicate that that the most common methods in the last 10 years for the reduction of variables is principal component analysis (PCA) and for indicators weighting is Analytic Hierarchy Process (AHP). The use of artificial neural networks (ANN) has been gaining ground in the last 10 years as a method for the spatial assessment of SEV. Other methods include dasymetric population mapping, factor analysis (FA), ordinal logistic regression (OLR), spatial multi-criteria evaluation (SMCE), and analytic network process (ANP). We also found hybrid methods that combine FA and ANP known as F'ANP, and others that combine fuzzy numbers with ANP, DEMATEL and PROMETHEE II (F-ADP). Other methods were simpler, such as an overlay analysis. The complete set of methods used by authors and identified in this systematic review is listed in Table 6.

METHODS	AUTHORS
PCA	Aksha, S. K., Resler, L. M., Juran, L., & Carstensen, L. W. (2020)
	Armaş, I., Toma-Danila, D., Ionescu, R., & Gavriş, A. (2017)
	Maharani, Y. N., Lee, S., & Ki, S. J. (2016)
	Toké, N. A., Boone, C. G., & Arrowsmith, J. R. (2014)
	Alcorn, R., Panter, K. S., & Gorsevski, P. V. (2013)
AHP	Aksha, S. K., Resler, L. M., Juran, L., & Carstensen, L. W. (2020)
	Alizadeh, M., Alizadeh, E., Kotenaee, S. A., Shahabi, H., Pour, A. B., Panahi, M., . . . Saro, L. (2018)
	Armaş, I., Toma-Danila, D., Ionescu, R., & Gavriş, A. (2017)
	Walker, B. B., Taylor-Noonan, C., Tabbernor, A., McKinnon, T. B., Bal, H., Bradley, D., . . . Clague, J. J. (2014)
ANN	Aksha, S. K., Resler, L. M., Juran, L., & Carstensen, L. W. (2020)
	Alizadeh, M., Alizadeh, E., Kotenaee, S. A., Shahabi, H., Pour, A. B., Panahi, M., . . . Saro, L. (2018)
	Maharani, Y. N., Lee, S., & Ki, S. J. (2016)
Dasymetric population mapping	Yuan, H. H., Gao, X. L., & Qi, W. (2019)
	Garcia, R. A. C., Oliveira, S. C., & Zezere, J. L. (2016)
FA	Castro, C. P., Ibarra, I., Lukas, M., Ortiz, J., & Sarmiento, J. P. (2015)
	Zebardast, E. (2013)
MCE	Walker, B. B., Taylor-Noonan, C., Tabbernor, A., McKinnon, T. B., Bal, H., Bradley, D., . . . Clague, J. J. (2014)
	Alcorn, R., Panter, K. S., & Gorsevski, P. V. (2013)
SMCE	Armaş, I., Toma-Danila, D., Ionescu, R., & Gavriş, A. (2017)
	Hizbaron, D. R., Baiquni, M., Sartohadi, J., & Rijanta, R. (2012)
F-ADP	Rezaei-Malek, M., Torabi, S. A., & Tavakkoli-Moghaddam, R. (2019)
OLR	Muir, J. A., Cope, M. R., Angeningsih, L. R., Jackson, J. E., & Brown, R. B. (2019)
Binary Logistic regression	Qasim, S., Qasim, M., Shrestha, R. P., & Khan, A. N. (2018)
Logical analysis method	Chen, Y. (2016)
Distance-based network analysis	Walker, B. B., Taylor-Noonan, C., Tabbernor, A., McKinnon, T. B., Bal, H., Bradley, D., . . . Clague, J. J. (2014)
Overlay analysis	Toké, N. A., Boone, C. G., & Arrowsmith, J. R. (2014)
F'ANP	Zebardast, E. (2013)

Table 6. Methods applied to the spatial assessment of socio-economic vulnerability (SEV).

The Social Vulnerability Index (SoVI®) remains the benchmark for the assessment of SEV and a reference for its spatial assessment. The complete set of spatial indexes used by authors and identified in this systematic review is listed in Table 7.

SPATIAL INDEXES	AUTHORS
SoVI®	Aksha, S. K., Resler, L. M., Juran, L., & Carstensen, L. W. (2020)
	Alcorn, R., Panter, K. S., & Gorsevski, P. V. (2013)
	Zebardast, E. (2013)
Population vulnerability Indexing	Yuan, H. H., Gao, X. L., & Qi, W. (2019)
LA-SoVIC	Toké, N. A., Boone, C. G., & Arrowsmith, J. R. (2014)

Table 7. Spatial indexes for socio-economic vulnerability (SEV) assessments.

The tools to carry out the spatial assessment of SEV were selected according to the identified spatial variable and indicators, the method used, and the indexes used, adapted, or developed. The most frequent tool for the spatial assessment of SEV is GIS, followed by statistical analyses undertaken in the statistical package for the social sciences (SPSS), remote sensing (RS) using the environment for visualizing images (ENVI), programming languages, and interactive databases such as the retrieval of data for small Areas by microcomputer (REDATAM)(CELADE, 2015). The complete list of tools used by the authors selected is found in Table 8.

METHOD	SOFTWARE	AUTHORS
GIS	ArcGIS	Aksha, S. K., Resler, L. M., Juran, L., & Carstensen, L. W. (2020).
		Yuan, H. H., Gao, X. L., & Qi, W. (2019)
		Alizadeh, M., Alizadeh, E., Kotenaee, S. A., Shahabi, H., Pour, A. B., Panahi, M., . . . Saro, L. (2018)
		Gautam, D. (2017)
		Castro, C. P., Ibarra, I., Lukas, M., Ortiz, J., & Sarmiento, J. P. (2015)
	IDRISI	Alizadeh, M., Alizadeh, E., Kotenaee, S. A., Shahabi, H., Pour, A. B., Panahi, M., . . . Saro, L. (2018)
	ILWIS	Armaş, I., Toma-Danila, D., Ionescu, R., & Gavriş, A. (2017)
	GeoDa Version 16.6	Ley-García, J., Denegri de Dios, F. M., & Ortega Villa, L. M. (2015)
	Not specified	Ponce-Pacheco, A. B., & Novelo-Casanova, D. A. (2018)
		Eidsvig, U. M. K., McLean, A., Vangelsten, B. V., Kalsnes, B., Ciurean, R. L., Argyroudis, S., . . . Kaiser, G. (2014)
		Toke, N. A., Boone, C. G., & Arrowsmith, J. R. (2014)
		Walker, B. B., Taylor-Noonan, C., Tabbernor, A., McKinnon, T., Bal, H., Bradley, D., . . . Clague, J. J. (2014)
		Alcorn, R., Panter, K. S., & Gorsevski, P. V. (2013)
		Hizbaron, D. R., Baiquni, M., Sartohadi, J., & Rijanta, R. (2012)
Statistical Analysis	SPSS 22.0	Aksha, S. K., Resler, L. M., Juran, L., & Carstensen, L. W. (2020)
	SPSS 16.0	Qasim, S., Qasim, M., Shrestha, R. P., & Khan, A. N. (2018)
	SPPS	Maharani, Y. N., Lee, S., & Ki, S. J. (2016)
		Castro, C. P., Ibarra, I., Lukas, M., Ortiz, J., & Sarmiento, J. P. (2015)
RS	ENVI	Alizadeh, M., Alizadeh, E., Kotenaee, S. A., Shahabi, H., Pour, A. B., Panahi, M., . . . Saro, L. (2018)
Programming language	MATLAB	Maharani, Y. N., Lee, S., & Ki, S. J. (2016)
Database	Redatam V5.0	Castro, C. P., Ibarra, I., Lukas, M., Ortiz, J., & Sarmiento, J. P. (2015)

Table 8. Tools used for the spatial assessment of socio-economic vulnerability (SEV) assessments.

5. Conclusions

Based on the evidence, we can state that most of the spatial assessments of SEV in urban environments have been done for earthquakes and landslides and that Indonesia, China, Iran, and the USA lead the research in spatial assessment of SEV related to geohazards in urban environments. The scale of the spatial level of assessment – namely global, continental, subcontinental, national, regional, provincial, municipal, or local – determines the type of data to be collected and the assessment approaches.

Although there have been advances, census data continues to be the most frequent source of data for the SEV assessments; however, in the case of spatial assessment, satellite images are now the main data source, facilitating the inclusion of the spatial component in SEV assessments. The spatial assessment of SEV allows visualising and communicating social phenomena and components that influence the degree of vulnerability that are not visible with other methods. The lack of data availability hinders the understanding of the concept of vulnerability (Zhou et al., 2014) and that is why VGI is essential today to obtain updated information in real-time at local scale, when other data sources are not available.

Traditional spatial variables and indicators continue to be used by authors, but combined with new variables, categories, and indicators, including the temporal dimension (day-night), and assessing at the local level, can increase the accuracy of spatial assessments of SEV and reduce uncertainty on their assessment. Each method for the spatial assessment of SV is selected according to the research aim, case study area, scale to cover, reliability of data sources, spatial variables and indicators available; geohazard to address, the scope of the research, and the level of funding. Methods such as ANN are gaining ground in the assessment of SEV. Other methods such as dasymetric population mapping enable more accurate SEV assessment. Factor analysis continues to be a useful tool to define the level of SEV based on primary dimensions and variables. Multi-criteria evaluation method offers a robust decision-making technique based on flexible choice and combination in criteria (Alcorn et al., 2013). SMCE incorporates the spatial component to the MCE to integrate spatial and non-spatial data to generate maps with multiple scenarios (Hizbaron et al., 2012). Classic methods such as FA are combined with more innovative ones such as ANP and fuzzy numbers to generate hybrid methods such as F'ANP. These new methods encourage the development of more complex hybrid methods such as F-ADP that increase the accuracy and reduce the uncertainty levels in the spatial SEV assessments. Ordinal logistic regression and binary logistic regression are useful methods to identify spatial variables as determinants of SEV. The spatial component can be also be added by simply overlapping the areas with high SEV with hazard zones using GIS. Most authors have built upon the SoVI® developed by Cutter et al. (2003) to quantify SEV or to create their own SEV indexes, demonstrating that it remains the benchmark for the assessment of SEV and a reference for its spatial assessment.

Geographic Information Systems, statistical analysis, RS, programming languages, and interactive databases are the tools currently used by the scientists for the assessment of SEV vulnerability. The spatial assessment of SEV in the areas where it is requested must depend not only on the financial resources for research but also on the availability of opensource software with the functionalities of spatial statistics, such as QGIS, GeoDa or Ilwis. Authors combine traditional and new data sources, spatial variables and indicators, methods, indexes and tools including the temporal dimension, increasing the resolution to the local level with the aim to increase the accuracy and reduce the uncertainty of spatial assessments of SEV related to geohazard in urban environments.

6 Recommendations

The development of a global spatial index of SEV is an urgent task, with the aim of making informed decisions about priority in funding prevention and mitigation actions related to geohazards in urban environments. In the meantime, the priority for these types of assessments must be allocated to developing countries with the lowest GDPs and increased levels of SV (Zhou et al., 2014). More spatial assessment of SEV due to volcanic eruptions and tsunamis in urban environments are needed, but also due to soil erosion and land degradation in the rural zones. Furthermore, the priority must be to allocate funding for countries with high SEV to enable the update of their census information, as this is the most frequent source of secondary data for any SEV assessment. It is also important to encourage the population to share information through social media (SM) about the vulnerable conditions in which they live, putting in practice the concept of citizen as a sensor (Cervone and Hultquist, 2018).

An assessment of SEV is a condition for the effective development of emergency management capabilities and to reduce the overall time for social recovery after an earthquake (Aubrecht et al., 2013;

Garcia et al., 2016). Likewise, spatial assessments of SEV must be considered before taking resettlement decisions for not creating again spatial conditions that favours the SEV. Authors such as Turvey (2007), Walker et al. (2014), Zhou et al. (2014) and Gautam (2017) highlight the need for place-specific, sub-provincial-level, neighbourhood-scale, or local level vulnerability indexes, due to geographic variations in population composition and social structures (Bell N et al., 2007). The macro-scale socio-economic assessment identifies general patterns but fails to capture the detail of the heterogeneity at the micro-scale. Thus, assessment at the provincial, county or state level can result in lost information (Zhou et al., 2014) or requires tackling issues such as ecological fallacy or MAUP (McLaughlin et al., 2002; Openshaw, 1983; Pacione, 2005). In the spatial assessment of SEV, it is necessary to go beyond the administrative boundaries or cartographic variables, with methods such as the dasymetric population mapping (Garcia et al., 2016; Yuan et al., 2019a), square mesh (Renard, 2017), pockets (Lin and Hung, 2016), or *geon* (Kienberger et al., 2009). We found interesting spatial indicators of SEV, such as population density based on land use (Zeng et al., 2012), which we consider more accurate than population density estimated at an area unit. This indicator can better integrate, using RS, the spatial dimension of the exposure and susceptibility of the population in the assessment of the SEV of a case study area. To improve the accuracy and reduce the uncertainty in spatial assessments of SEV must always be the aim. The presence of urban facilities must be included in the assessment of SV. Walker et al. (2014) suggest developing a weighted 'local resource' index for assessing systemic vulnerability since, for example, the absence of sports facilities is associated by Iguacel et al. (2018), Vandermeerschen, Vos, & Scheerder (2015), and Aguilar-Palacio, Gil-Lacruz and Gil-Lacruz (2013) with high levels of SV. In the spatial assessment of SEV, it is also necessary to consider the influence of the spatial component represented by physical space in the degree of vulnerability of a specific area, such as the relationship between slums and a low degree of wellness and health (Buzai and Villerías Alarcón, 2018).

It is necessary to take advantage of the versatility of methods such as ANN based on machine learning to make progress in the spatial assessment of SEV and SMCE in order to map multiple scenarios to inform urban communities and to integrate them in the decision making processes. Communities respond differently to vulnerability maps depending on the purpose behind the maps or the cultural background of the community. On the one hand, some communities reject being mapped as 'victims', but on the other hand, some request being identified as highly vulnerable to gain access to funding opportunities for activities of risk management (Fekete, 2012). The Walk Score® index developed by Bereitschaft (2017a) although originally orientated to measure only neighbourhood walkability (Bereitschaft, 2017b), could be adapted as a tool to either complement or validate any spatial index for assessing SEV at the local level. The advantage over the SoVI® is that while the SoVI® can be spatialised, Walk Score® is a 3D high resolution spatial index *per se*. The use of the local scale for the assessment of SV will be more useful for the planning of resilient actions (Lee, 2014; Maharani et al., 2016) than would be vulnerability assessment at a regional scale, which is more orientated to the collection of pathologies in the social dimension. It is necessary to more closely examine so-called 'proxy indicators' to measure SV at micro-local scales or intra-city levels (Gu et al., 2018). The right management of the spatial component by a community can reduce its economic vulnerability. Groß (2017) presented the case of ski-lift entrepreneurs in Vorarlberg (Austria) who reduced the probability of business interruption by accelerating the uphill and downhill flows of people through manipulating snow and topography. Regarding tools, it is necessary to take full advantage of the functionalities of opensource software such as and QGIS and ILWIS to make the spatial assessment of SEV to the reach of all the scientific communities around the world.

Again, we are most appreciative of the attention and care you have given to our manuscript, and we hope you will now consider it for minor revisions and eventually for publication.

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Yuan, H. H., Gao, X. L., and Qi, W.: Modeling the fine-scale spatiotemporal pattern of earthquake casualties in cities: Application to Haidian District, Beijing, International Journal of Disaster Risk Reduction, 34, 412-422, 2019b.
Zebardast, E.: Constructing a social vulnerability index to earthquake hazards using a hybrid factor analysis and analytic network process (F'ANP) model, Nat. Hazards, 65, 1331-1359, 2013.
Zeng, J., Zhu, Z. Y., Zhang, J. L., Ouyang, T. P., Qiu, S. F., Zou, Y., and Zeng, T.: Social vulnerability assessment of natural hazards on county-scale using high spatial resolution satellite imagery: a case study in the Luogang district of Guangzhou, South China, Environmental Earth Sciences, 65, 173-182, 2012.
Zhang, N. and Huang, H.: Assessment of world disaster severity processed by Gaussian blur based on large historical data: casualties as an evaluating indicator, Nat. Hazards, 92, 173-187, 2018.
Zhou, Y., Li, N., Wu, W., Wu, J., and Shi, P.: Local Spatial and Temporal Factors Influencing Population and Societal Vulnerability to Natural Disasters, Risk Analysis, 34, 614-639, 2014.

Reviewer 1

Thank you very much for your observations. You kindly spent time delving into our manuscript, and we are grateful. We have used a colour code to answer your questions. Please find your comments in grey, and the respective answers in black. The corresponding paragraph in the paper is in dark blue.

Comments

- Using one of the leading databases on scientific journal publications, the authors performed an assessment of articles published between 2008 and 2018 addressing the social and economic dimensions of vulnerability. From originally 235 articles, 21 were finally chosen for a detailed analysis. However, while the authors initially stated to undertake a systematic review for an application on an urban scale, the results and conclusions do not necessarily mirror this aim.

  Thank you for your observation. A systematic review searches for, appraises and synthesises research evidence (Grant and Booth, 2009). Initially, the time period selected for the systematic review was 2008-2018, but as we are interested in elucidating the state of the art in data sources, spatial variables, indicators, methods, indexes and tools for the spatial assessment of the socio-economic vulnerability (SEV) related to geohazards in urban environments we decided to re-run the query updating also the period from 2010 to 2020. This time we undertook the search not only in Clarivate but also in two more databases: Scopus/Elsevier and Google scholar. Following the request of the reviewers we decided to include in this revised version the complete list of inclusion and exclusion search terms, that was not included in the previous version as a suggestion of one of the co-authors. Please find the search terms considered in Table 1.

D	**Q**	**SEARCH TERMS**
Clarivate analytics	TOPIC	“social vulnerability” OR “economic vulnerability” OR “socioeconomic vulnerability” OR “socio-economic vulnerability”
		AND
	TOPIC	“area” OR “distance” OR “range” OR “distance” OR “direction” OR “spatial geometries” OR “patterns” OR “spatial connectivity” OR “isolation” OR “diffusion” OR “spatial association” OR “scale” OR “accessibility” OR “network” OR “cluster”
		AND
	TOPIC	“earthquakes” OR “tsunamis” OR “volcanic eruptions” OR “landslides” OR “soil erosion” OR “land degradation”
		NOT
	TOPIC	“climate change” OR “ecological” OR “drought” OR “resilience” OR “debris” OR “epidemiological” OR “substance” OR “behavioural” OR “evacuation” OR “recovery” OR “pollution” OR “leptospirosis” OR “violence” OR “illness” OR “disease” OR “heat” OR “crisis” OR “conflict” OR “deaths” OR “obesity” OR “criminal” OR “chemical” OR “symptoms” OR “syndrome” OR “food insecurity” OR “air pollution” OR “stress” OR “diabetes” OR “depressive” OR “alcohol” OR “cancer” OR “drugs” OR “palm oil” OR “tobacco” OR “smoke” OR “storm” OR “psychometric” OR “cocaine” OR “toxic” OR “palliative” OR “therapy” OR “HIV” OR “dengue” OR “ecosystem” OR “rheumatoid” “arthritis” OR “nutritional” OR “malaria” OR “resources” OR “sexual activity” OR “sexual health”

Art

D	Q	SEARCH TERMS
Scopus/Elsevier		(TITLE-ABS-KEY (“social vulnerability*” AND “economic vulnerability*”) AND TITLE-ABS-KEY (“socioeconomic vulnerability*”) AND TITLE-ABS-KEY (“area” OR “distance” OR “range” OR “distance” OR “direction” OR “spatial geometries” OR “patterns” OR “spatial connectivity” OR “isolation” OR “diffusion” OR “spatial association” OR “scale” OR “accessibility” OR “network” OR “cluster”) AND TITLE-ABS-KEY (“earthquakes” OR “tsunamis” OR “volcanic eruptions” OR “landslides” OR “soil erosion” OR “land degradation”) AND NOT TITLE-ABS-KEY (“climate change” OR “ecological” OR “drought” OR “resilience” OR “debris” OR “epidemiological” OR “substance” OR “behavioral” OR “evacuation” OR “recovery” OR “pollution” OR “leptospirosis” OR “violence” OR “illness” OR “disease”)) AND DOCTYPE (ar) AND PUBYEAR > 2009 AND PUBYEAR <2021

D: Database
Q: Query
Table 1. Terms included and excluded to select relevant literature references in Clarivate analytics.

Google scholar was discarded as a source of references given that when the query was run on this database, it gave us only one reference, which was the first version of this manuscript. Please see the evidence below in Figure 1.

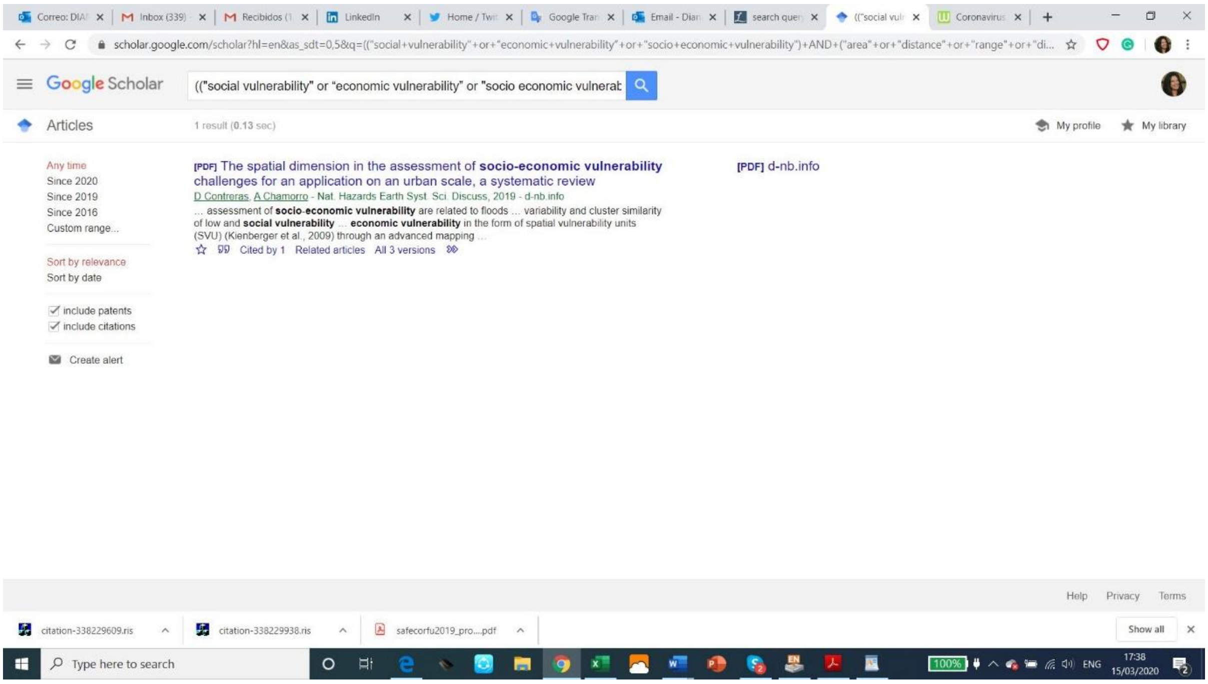

Figure 1. Evidence of the result of the search query on the Google Scholar database.

- From their final choice of contributions, the main conclusion of the authors is that for assessing social vulnerability it is not sufficient to only compute a specific level of vulnerability, but also to include other spatial information available in order to avoid the modifiable areal unit problem (e.g., Unwin 1996).

Thanks for suggesting us this reference:

Unwin, D. J. (1996). GIS, spatial analysis and spatial statistics. Progress in Human Geography, 20(4), 540-551. doi:10.1177/030913259602000408

The section of conclusions has been revisited. Then, we invite you to check the new version. Please read below:

5 Conclusions

Based on the evidence, we can state that most of the spatial assessments of SEV in urban environments have been done for earthquakes and landslides and that Indonesia, China, Iran, and the USA lead the research in spatial assessment of SEV related to geohazards in urban environments. The scale of the spatial level of assessment – namely global, continental, subcontinental, national, regional, provincial, municipal, or local – determines the type of data to be collected and the assessment approaches. Although there have been advances, census data continues to be the most frequent source of data for the SEV assessments; however, in the case of spatial assessment, satellite images are now the main data source, facilitating the inclusion of the spatial component in SEV assessments. The spatial assessment of SEV allows visualising and communicating social phenomena and components that influence the degree of vulnerability that are not visible with other methods. The lack of data availability hinders the understanding of the concept of vulnerability (Zhou et al., 2014) and that is why VGI is essential today to obtain updated information in real-time at local scale, when other data sources are not available.

Traditional spatial variables and indicators continue to be used by authors, but combined with new variables, categories, and indicators, including the temporal dimension (day-night), and assessing at the local level, can increase the accuracy of spatial assessments of SEV and reduce uncertainty on their assessment. Each method for the spatial assessment of SV is selected according to the research aim, case study area, scale to cover, reliability of data sources, spatial variables and indicators available; geohazard to address, the scope of the research, and the level of funding. Methods such as ANN are gaining ground in the assessment of SEV. Other methods such as dasymetric population mapping enable more accurate SEV assessment. Factor analysis continues to be a useful tool to define the level of SEV based on primary dimensions and variables. Multi-criteria evaluation method offers a robust decision-making technique based on flexible choice and combination in criteria (Alcorn et al., 2013). SMCE incorporates the spatial component to the MCE to integrate spatial and non-spatial data to generate maps with multiple scenarios (Hizbaron et al., 2012). Classic methods such as FA are combined with more innovative ones such as ANP and fuzzy numbers to generate hybrid methods such as F'ANP. These new methods encourage the development of more complex hybrid methods such as F-ADP that increase the accuracy and reduce the uncertainty levels in the spatial SEV assessments. Ordinal logistic regression and binary logistic regression are useful methods to identify spatial variables as determinants of SEV. The spatial component can be also be added by simply overlapping the areas with high SEV with hazard zones using GIS. Most authors have built upon the SoVI® developed by Cutter et al. (2003) to quantify SEV or to create their own SEV indexes, demonstrating that it remains the benchmark for the assessment of SEV and a reference for its spatial assessment.

Geographic Information Systems, statistical analysis, RS, programming languages, and interactive databases are the tools currently used by the scientists for the assessment of SEV vulnerability. The spatial assessment of SEV in the areas where it is requested must depend not only on the financial resources for research but also on the availability of opensource software with the functionalities of spatial statistics, such as QGIS, GeoDa or Ilwis. Authors combine traditional and new data sources, spatial variables and indicators, methods, indexes and tools including the temporal dimension, increasing the resolution to the local level with the aim to increase the accuracy and reduce the uncertainty of spatial assessments of SEV related to geohazard in urban environments.

- The overall choice of keywords and exclusion of other keywords results in the fact that many studies addressing social vulnerability and/or economic dimensions of vulnerability have not been considered by the authors, which in turn restricts the overall conclusions possible.

Thanks for your comment. We agreed that there are many studies addressing SEV and/or economic dimensions, but not all of them consider the spatial dimension, which is the main aim of this research. The conclusions have been revisited as you could check in the previous section. The 23 references finally reviewed are listed in Table 2.

AUTHOR	YEAR	RESEARCH OBJECTIVE	HAZARD	COUNTRY
Aksha, S. K., Resler, L. M., Juran, L., & Carstensen, L. W.	2020	To introduce a model for spatial multi-hazards risk assessment applied to Dharan, Nepal.	Earthquakes, floods and landslides	Nepal
Kurnianto, F. A., Ikhsan, F. A., Apriyanto, B., & Nurdin, E. A. (2019)	2019	To assess the level of vulnerability for an earthquake disaster in Lembang district, an area in West Java that includes the Bandung basin	Earthquakes	Indonesia
Muir, J. A., Cope, M. R., Angeningsih, L. R., Jackson, J. E., & Brown, R. B.	2019	To explore whether return migration, compared to other migration options, results in superior improvements to mental health in the context of disasters.	Volcanic eruptions	Indonesia
Rezaei-Malek, M., Torabi, S. A., & Tavakkoli-Moghaddam, R.	2019	To prioritize disaster-prone areas which are known as potential demand points (PDPs) given their vulnerability under large-scale earthquakes	Earthquakes	Iran
Yuan, H. H., Gao, X. L., & Qi, W. (2019)	2019	To provide high spatial-temporal resolution information on vulnerable populations and population vulnerability using dasymetric population mapping with vulnerability index	Earthquakes	China
Alizadeh, M., Alizadeh, E., Kotenaee, S. A., Shahabi, H., Pour, A. B., Panahi, M., . . . Saro, L.	2018	To apply an artificial neural network (ANN) and geographic information system (GIS) for estimating the social vulnerability to earthquakes in the Tabriz city, Iran.	Earthquakes	Iran
Qasim, S., Qasim, M., Shrestha, R. P., & Khan, A. N.	2018	To define the socio-economic determinants of landslide risk perception in Murree hills of Pakistan.	Landslides	Pakistan
Ponce-Pacheco, A. B., & Novelo-Casanova, D. A.	2018	To estimate the levels of vulnerability and risk to floods, earthquakes and subsidence of Valle de Chalco Solidaridad (VCS) in Mexico	Earthquakes, floods and subsidence	Mexico
Armaş, I., Toma-Danila, D., Ionescu, R., & Gavriş, A.	2017	To develop an overall vulnerability index to seismic hazard based on a spatial approach applied to Bucharest, Romania.	Earthquakes	Romania
Gautam, D.	2017	To investigates social vulnerability to natural hazards in Nepal at district level.	Droughts, earthquakes, epidemics floods and landslides,	Nepal
Chen, Y.	2016	To develop a set of valid and reliable indicators to evaluate the regional land subsidence disaster vulnerability in the Xixi-Chengnan area, in China.	Landslides	China
Garcia, R. A. C., Oliveira, S. C., & Zezere, J. L.	2016	To apply dasymetric cartography to improving population spatial resolution and to assess the potentially exposed population over large areas to deep rotational landslides and compare the results with those obtained with basic census units as the data source	Landslides	Portugal

AUTHOR	YEAR	RESEARCH OBJECTIVE	HAZARD	COUNTRY
Maharani, Y. N., Lee, S., & Ki, S. J.	2016	To propose the use of Self-Organizing Maps (SOM) approach to conducting the social vulnerability assessment around the Merapi volcano.	Volcanic eruptions	Indonesia
Castro, C. P., Ibarra, I., Lukas, M., Ortiz, J., & Sarmiento, J. P.	2015	To assess the social vulnerability of informal settlements in Iquique and Puerto Montt in Chile	Earthquakes, floods, landslides and Tsunami	Chile
Ley-García, J., Denegri de Dios, F. M., & Ortega Villa, L. M.	2015	The aim is to identify visibility, invisibility and amplification of hazardscape perception in the city of Mexicali, Baja California, Mexico.	Earthquake Landslide Tsunami Volcano Cyclone Thunderstorm Heavy rainfall Flood hail Snow-freeze Strong wind Drought Cold wave Heat wave	Mexico
Eidsvig, U. M. K., McLean, A., Vangelsten, B. V., Kalsnes, B., Ciurean, R. L., Argyroudis, S., . . . Kaiser, G.	2014	To propose a methodology to estimate socioeconomic vulnerability to landslides at the local to regional scale using an indicator-based model	Landslides	Andorra, France, Greece, Norway, and Romania
Toké, N. A., Boone, C. G., & Arrowsmith, J. R.	2014	To construct a relative social vulnerability index classification for Los Angeles to examine the social condition within regions of significant seismic hazard, including areas regulated as Alquist-Priolo (AP) Act earthquake fault zones.	Earthquakes landslides and wildfires	USA
Walker, B. B., Taylor-Noonan, C., Tabbernor, A., McKinnon, T. B., Bal, H., Bradley, D., . . . Clague, J. J.	2014	To model geophysical processes and identification of socio-economically disadvantaged populations in Victoria, British Columbia.	Earthquakes	Canada
Alcorn, R., Panter, K. S., & Gorsevski, P. V.	2013	To evaluate the spatial impact of a possible future eruption using a GIS-based volcanic hazard tool and to assess the social and economic vulnerabilities of the area at risk.	Volcanic eruption	USA
Aubrecht, C., Özceylan, D., Steinnocher, K., & Freire, S.	2013	To review available multi-level geospatial information and modelling approaches from local to global scales, that could serve practitioners and researchers in disaster-related zones	Tsunami, floods	Austria Portugal Turkey USA
Zebardast, E.	2013	To develop a model that combines hybrid factor analysis and analytic network process (F'ANP) for constructing a composite social vulnerability index (SOVI)	Earthquakes	Iran
Hizbaron, D. R., Baiquni, M., Sartohadi, J., & Rijanta, R.	2012	To assess urban vulnerability due to seismic hazard using a risk based spatial plan	Earthquakes	Indonesia
Zeng, J., Zhu, Z. Y., Zhang, J. L., Ouyang, T. P., Qiu, S. F., Zou, Y., & Zeng, T.	2012	To introduce a new method to assess social vulnerability for county-scale regions using population density, based on land use.	Landslides	China

Table 2. Articles identified and selected by the systematic review.

- The time period covered is not justified

Thank you for this observation. The reason for selecting the period 2008–2018 and update the period to 2010-2020 for this revised version was to explore the state of the art on data sources, spatial variables, indicators, methods, indexes and tools for the assessment of SEV related to geohazards in urban environments which we believe can be covered in the past 10 years. We included this clarification in the methods section of the revised version of the manuscript. Additionally, in the introduction and the discussion section, we included relevant references before this period following a request of the editor. Please find below the correspondent text below:

'(…) A systematic review searches for, appraises, and synthesises research evidence (Grant and Booth, 2009). In the present research, the systematic review was conducted to elucidate the state of the art of data sources, spatial variables, indicators, methods, indexes and tools for the spatial assessment of the SEV related to geohazards, which we consider is covered in the period between 2010 and 2020. Thus, the main research question is: what is the state of the art in the spatial assessment of SEV to geohazards in urban environments? (…)'

- The overall aim to provide a structured overview on studies and indicators, which is not only promised in the title of the contribution but also in the introduction, is not mirrored by the main text body. Materials, methods and findings are rather compiled in a very unstructured way which makes a structured conclusion quite challenging.

Thank you for your observation. We are afraid that we do not have a materials section. The data sources, spatial variables, indicators, methods, indexes and tools, which we believe you named 'findings', are listed in tables. The structure of the tables is explained in the methods section. Please find the explanation below:

'(…) The findings will be presented in the results section in tables related to selected references, data sources, spatial variables, indicators, methods, spatial indexes, and tools. Table 2 is structured in four columns, namely author, year, research objective, geohazard addressed, and country where the case study area of the paper is located. The authors are listed from the most recent reference to the oldest one. Tables 3, 4, 5, 6 and 7 are structured mainly in two columns: the first column lists data sources, spatial variables, indicators, methods and indexes respectively. The second column contains the authors and the year of their publications, in which the mentioned topics are addressed. Moreover, the references in these tables are also listed in reverse chronological order. Table 7 includes three columns, namely, method, software and authors (…)'.

The tables with the findings are below:

DATA SOURCES		AUTHORS
Census data	Nepal census	Aksha, S. K., Resler, L. M., Juran, L., & Carstensen, L. W. (2020)
		Ponce-Pacheco, A. B., & Novelo-Casanova, D. A. (2018)
	City office of Dharan	Aksha, S. K., Resler, L. M., Juran, L., & Carstensen, L. W. (2020)
	National Institute of Statistics and Geography	Ponce-Pacheco, A. B., & Novelo-Casanova, D. A. (2018)

	DATA SOURCES	AUTHORS
	Municipal Government of Valle de Chalco Solidaridad	Ponce-Pacheco, A. B., & Novelo-Casanova, D. A. (2018)
	Secretariat of Social Development of Mexico	Ponce-Pacheco, A. B., & Novelo-Casanova, D. A. (2018)
	CBS 2011 Census	Gautam, D. (2017)
	Xishan and Huishan Statistical Yearbook 2008	Chen, Y. (2016)
	Population and Housing Census 2010	Lin, W.-Y., & Hung, C.-T. (2016)
	National Census 2011	Garcia, R. A. C., Oliveira, S. C., & Zezere, J. L. (2016)
	Statistics of Sleman Regency https://slemankab.bps.go.id/	Maharani, Y. N., Lee, S., & Ki, S. J. (2016)
	National census of population and VI of housing	Castro, C. P., Ibarra, I., Lukas, M., Ortiz, J., & Sarmiento, J. P. (2015).
	2000 U.S. Census Bureau	Toké, N. A., Boone, C. G., & Arrowsmith, J. R. (2014)
	Statistical Office of Baden-Wuerttemberg	Khazai, B., Merz, M., Schulz, C., & Borst, D. (2013)
	Regional Planning Board	Hizbaron, D. R., Baiquni, M., Sartohadi, J., & Rijanta, R. (2012)
	Statistical Bureau	Hizbaron, D. R., Baiquni, M., Sartohadi, J., & Rijanta, R. (2012)
	Armaş, I., Toma-Danila, D., Ionescu, R., & Gavriş, A. (2017)	
	Garcia, R. A. C., Oliveira, S. C., & Zezere, J. L. (2016)	
	Walker, B. B., Taylor-Noonan, C., Tabbernor, A., McKinnon, T. B., Bal, H., Bradley, D., . . . Clague, J. J. (2014)	
Satellite images	WorldView-3	Aksha, S. K., Resler, L. M., Juran, L., & Carstensen, L. W. (2020)
	ASTER-DEM	Aksha, S. K., Resler, L. M., Juran, L., & Carstensen, L. W. (2020)
	PERSIANN-CDR	Aksha, S. K., Resler, L. M., Juran, L., & Carstensen, L. W. (2020)
	Google Earth satelllite images	Castro, C. P., Ibarra, I., Lukas, M., Ortiz, J., & Sarmiento, J. P. (2015)
	GDEM-ASTER	Castro, C. P., Ibarra, I., Lukas, M., Ortiz, J., & Sarmiento, J. P. (2015)
	LANDSAT	Toké, N. A., Boone, C. G., & Arrowsmith, J. R. (2014)
	LANDSAT™	Aubrecht, C., Özceylan, D., Steinnocher, K., & Freire, S. (2013)
	SPOT	Zeng, J., Zhu, Z. Y., Zhang, J. L., Ouyang, T. P., Qiu, S. F., Zou, Y., & Zeng, T. (2012)
Satellite images	IKONOS	Aubrecht, C., Özceylan, D., Steinnocher, K., & Freire, S. (2013)
	NDVI	Aubrecht, C., Özceylan, D., Steinnocher, K., & Freire, S. (2013)

	DATA SOURCES	AUTHORS
Field Observations	Alizadeh, M., Alizadeh, E., Kotenaee, S. A., Shahabi, H., Pour, A. B., Panahi, M., . . . Saro, L. (2018)	
	Ponce-Pacheco, A. B., & Novelo-Casanova, D. A. (2018)	
	Garcia, R. A. C., Oliveira, S. C., & Zezere, J. L. (2016)	
	Castro, C. P., Ibarra, I., Lukas, M., Ortiz, J., & Sarmiento, J. P. (2015)	
	Hizbaron, D. R., Baiquni, M., Sartohadi, J., & Rijanta, R. (2012)	
Disaster Databases	Indonesian Disaster Data Information (DIBI) http://dibi.bnpb.go.id/dibi/	Maharani, Y. N., Lee, S., & Ki, S. J. (2016)
	Risk Atlas of the Municipality of Mexicali 2011	Ley-García, J., Denegri de Dios, F. M., & Ortega Villa, L. M. (2015)
	Desinventar Data Base	Ponce-Pacheco, A. B., & Novelo-Casanova, D. A. (2018)
Surveys	Muir, J. A., Cope, M. R., Angeningsih, L. R., Jackson, J. E., & Brown, R. B. (2019)	
	Ponce-Pacheco, A. B., & Novelo-Casanova, D. A. (2018)	
	Qasim, S., Qasim, M., Shrestha, R. P., & Khan, A. N. (2018).	
Aerial Photograph	Castro, C. P., Ibarra, I., Lukas, M., Ortiz, J., & Sarmiento, J. P. (2015)	
	Toké, N. A., Boone, C. G., & Arrowsmith, J. R. (2014)	
LULC maps	CORINE	Aubrecht, C., Özceylan, D., Steinnocher, K., & Freire, S. (2013)
	HR Soil sealing layer	Aubrecht, C., Özceylan, D., Steinnocher, K., & Freire, S. (2013)
Population datasets	GPW/GPWv4	Aubrecht, C., Özceylan, D., Steinnocher, K., & Freire, S. (2013)
	GRUMP	Aubrecht, C., Özceylan, D., Steinnocher, K., & Freire, S. (2013)
Landslide susceptibility map (pixel terrain unit)	Garcia, R. A. C., Oliveira, S. C., & Zezere, J. L. (2016)	
Orthophoto	Armaş, I., Toma-Danila, D., Ionescu, R., & Gavriş, A. (2017)	
VGI	Aubrecht, C., Özceylan, D., Steinnocher, K., & Freire, S. (2013)	

Table 3. Data sources for the spatial assessment of socio-economic vulnerability (SEV).

SPATIAL VARIABLES	AUTHORS
Households without piped water connection, electricity, sewerage infrastructure, cell phone or landline	Aksha, S. K., Resler, L. M., Juran, L., & Carstensen, L. W. (2020)
	Ponce-Pacheco, A. B., & Novelo-Casanova, D. A. (2018)
	Gautam, D. (2017)
	Castro, C. P., Ibarra, I., Lukas, M., Ortiz, J., & Sarmiento, J. P. (2015)
	Zebardast, E. (2013)
Location	Kurnianto, F. A., Ikhsan, F. A., Apriyanto, B., & Nurdin, E. A. (2019)
	Muir, J. A., Cope, M. R., Angeningsih, L. R., Jackson, J. E., & Brown, R. B. (2019)

SPATIAL VARIABLES	AUTHORS
	Qasim, S., Qasim, M., Shrestha, R. P., & Khan, A. N. (2018)
	Castro, C. P., Ibarra, I., Lukas, M., Ortiz, J., & Sarmiento, J. P. (2015)
Critical facilities (fire stations, hospitals, health services, medical emergency services, medical facilities, etc.)	Rezaei-Malek, M., Torabi, S. A., & Tavakkoli-Moghaddam, R. (2019)
	Ponce-Pacheco, A. B., & Novelo-Casanova, D. A. (2018)
	Eidsvig, U. M. K., McLean, A., Vangelsten, B. V., Kalsnes, B., Ciurean, R. L., Argyroudis, S., . . . Kaiser, G. (2014)
	Alcorn, R., Panter, K. S., & Gorsevski, P. V. (2013)
	Zeng, J., Zhu, Z. Y., Zhang, J. L., Ouyang, T. P., Qiu, S. F., Zou, Y., & Zeng, T. (2012)
Distance from faults/ causative faults	Rezaei-Malek, M., Torabi, S. A., & Tavakkoli-Moghaddam, R. (2019)
	Hizbaron, D. R., Baiquni, M., Sartohadi, J., & Rijanta, R. (2012)
Household with low quality and/or precarious external walls, roofing and floors	Aksha, S. K., Resler, L. M., Juran, L., & Carstensen, L. W. (2020)
	Castro, C. P., Ibarra, I., Lukas, M., Ortiz, J., & Sarmiento, J. P. (2015)
Total area of occupied space in the residences	Armaş, I., Toma-Danila, D., Ionescu, R., & Gavriş, A. (2017)
	Zeng, J., Zhu, Z. Y., Zhang, J. L., Ouyang, T. P., Qiu, S. F., Zou, Y., & Zeng, T. (2012)
Schools	Alcorn, R., Panter, K. S., & Gorsevski, P. V. (2013)
	Zeng, J., Zhu, Z. Y., Zhang, J. L., Ouyang, T. P., Qiu, S. F., Zou, Y., & Zeng, T. (2012)
Families occupying rented houses	Aksha, S. K., Resler, L. M., Juran, L., & Carstensen, L. W. (2020)
Households per housing unit	Zebardast, E. (2013)
Households with >1 family	Aksha, S. K., Resler, L. M., Juran, L., & Carstensen, L. W. (2020)
City blocks	Yuan, H. H., Gao, X. L., & Qi, W. (2019)
Displaced, moved home, in transition, moved on	(Muir et al., 2019), J. A., Cope, M. R., Angeningsih, L. R., Jackson, J. E., & Brown, R. B. (2019)
Distance to volcanoes	Kurnianto, F. A., Ikhsan, F. A., Apriyanto, B., & Nurdin, E. A. (2019)
Availability of evacuation roads	Ponce-Pacheco, A. B., & Novelo-Casanova, D. A. (2018)
Housing occupation type/tenancy condition	Castro, C. P., Ibarra, I., Lukas, M., Ortiz, J., & Sarmiento, J. P. (2015)
Average household size	Toke, N. A., Boone, C. G., & Arrowsmith, J. R. (2014)
Housing type	Eidsvig, U. M. K., McLean, A., Vangelsten, B. V., Kalsnes, B., Ciurean, R. L., Argyroudis, S., . . . Kaiser, G. (2014)
Percentage of households with public assistance	Toke, N. A., Boone, C. G., & Arrowsmith, J. R. (2014)
Percent of workers with a long commute	Toke, N. A., Boone, C. G., & Arrowsmith, J. R. (2014)
Travel barriers to the trauma centres	Walker, B. B., Taylor-Noonan, C., Tabbernor, A., McKinnon, T. B., Bal, H., Bradley, D., . . . Clague, J. J. (2014)
Travel distance to trauma centres	Walker, B. B., Taylor-Noonan, C., Tabbernor, A., McKinnon, T. B., Bal, H., Bradley, D., . . . Clague, J. J. (2014)

SPATIAL VARIABLES	AUTHORS
Travel time to trauma centres	Walker, B. B., Taylor-Noonan, C., Tabbernor, A., McKinnon, T. B., Bal, H., Bradley, D., . . . Clague, J. J. (2014)
Walking time to trauma centres	Walker, B. B., Taylor-Noonan, C., Tabbernor, A., McKinnon, T. B., Bal, H., Bradley, D., . . . Clague, J. J. (2014)
Land use	Alcorn, R., Panter, K. S., & Gorsevski, P. V. (2013)
Housing with bathroom	Zebardast, E. (2013)
Housing with kitchen	Zebardast, E. (2013)
Migration status	Muir, J. A., Cope, M. R., Angeningsih, L. R., Jackson, J. E., & Brown, R. B. (2019)
Road type	Alcorn, R., Panter, K. S., & Gorsevski, P. V. (2013)
Spatial distribution of cell phone subscribers	Aubrecht, C., Özceylan, D., Steinnocher, K., & Freire, S. (2013)
Distance to hospital	Zeng, J., Zhu, Z. Y., Zhang, J. L., Ouyang, T. P., Qiu, S. F., Zou, Y., & Zeng, T. (2012)
Distance to road network	Hizbaron, D. R., Baiquni, M., Sartohadi, J., & Rijanta, R. (2012)
Distance to trauma centres	Walker, B. B., Taylor-Noonan, C., Tabbernor, A., McKinnon, T. B., Bal, H., Bradley, D., . . . Clague, J. J. (2014)
Distribution of urban greenspace	Toké, N. A., Boone, C. G., & Arrowsmith, J. R. (2014)
Industry land, Office land and commercial. residential land and park space	Zeng, J., Zhu, Z. Y., Zhang, J. L., Ouyang, T. P., Qiu, S. F., Zou, Y., & Zeng, T. (2012)
Population dependent on the land for the primary source of income	Eidsvig, U. M. K., McLean, A., Vangelsten, B. V., Kalsnes, B., Ciurean, R. L., Argyroudis, S., . . . Kaiser, G. (2014).
Road network	Zeng, J., Zhu, Z. Y., Zhang, J. L., Ouyang, T. P., Qiu, S. F., Zou, Y., & Zeng, T. (2012)

Table 4. Spatial variables for socio-economic vulnerability (SEV) assessments.

SPATIAL INDICATORS	AUTHORS
Population density (women/men density)	Alizadeh, M., Alizadeh, E., Kotenaee, S. A., Shahabi, H., Pour, A. B., Panahi, M., . . . Saro, L. (2018)
	Kurnianto, F. A., Ikhsan, F. A., Apriyanto, B., & Nurdin, E. A. (2019)
	Yuan, H. H., Gao, X. L., & Qi, W. (2019)
	Alizadeh, M., Alizadeh, E., Kotenaee, S. A., Shahabi, H., Pour, A. B., Panahi, M., . . . Saro, L. (2018)
	Armaş, I., Toma-Danila, D., Ionescu, R., & Gavriş, A. (2017)
	Chen, Y. (2016)
	Maharani, Y. N., Lee, S., & Ki, S. J. (2016)
	Eidsvig, U. M. K., McLean, A., Vangelsten, B. V., Kalsnes, B., Ciurean, R. L., Argyroudis, S., . . . Kaiser, G. (2014)
	Toké, N. A., Boone, C. G., & Arrowsmith, J. R. (2014)
	Hizbaron, D. R., Baiquni, M., Sartohadi, J., & Rijanta, R. (2012)
	Zeng, J., Zhu, Z. Y., Zhang, J. L., Ouyang, T. P., Qiu, S. F., Zou, Y., & Zeng, T. (2012)
Housing density	Alizadeh, M., Alizadeh, E., Kotenaee, S. A., Shahabi, H., Pour, A. B., Panahi, M., . . . Saro, L. (2018)

SPATIAL INDICATORS	AUTHORS
	Armaş, I., Toma-Danila, D., Ionescu, R., & Gavriş, A. (2017)
	Toké, N. A., Boone, C. G., & Arrowsmith, J. R. (2014)
Hospital beds per 1,000 people	Eidsvig, U. M. K., McLean, A., Vangelsten, B. V., Kalsnes, B., Ciurean, R. L., Argyroudis, S., . . . Kaiser, G. (2014)
	Zebardast, E. (2013)
Living space pp	Armaş, I., Toma-Danila, D., Ionescu, R., & Gavriş, A. (2017)
	Zebardast, E. (2013)
Degree of population aglomeration	Yuan, H. H., Gao, X. L., & Qi, W. (2019)
Floating population	Yuan, H. H., Gao, X. L., & Qi, W. (2019)
Mobility	Yuan, H. H., Gao, X. L., & Qi, W. (2019)
Spatial distribution	Yuan, H. H., Gao, X. L., & Qi, W. (2019)
Employed/ Unemployed density	Alizadeh, M., Alizadeh, E., Kotenaee, S. A., Shahabi, H., Pour, A. B., Panahi, M., . . . Saro, L. (2018).
Household overcrowding	Ponce-Pacheco, A. B., & Novelo-Casanova, D. A. (2018)
Literate people density	Alizadeh, M., Alizadeh, E., Kotenaee, S. A., Shahabi, H., Pour, A. B., Panahi, M., . . . Saro, L. (2018)
BCU target zones	Garcia, R. A. C., Oliveira, S. C., & Zezere, J. L. (2016)
BCU population	Garcia, R. A. C., Oliveira, S. C., & Zezere, J. L. (2016)
Density of agricultural/industrial production	Chen, Y. (2016)
Farming density	Chen, Y. (2016)
GDP density	Chen, Y. (2016)
Investment density of fixed assets	Chen, Y. (2016)
Global Moran's I	Ley-García, J., Denegri de Dios, F. M., & Ortega Villa, L. M. (2015)
LISA	Ley-García, J., Denegri de Dios, F. M., & Ortega Villa, L. M. (2015)
Access to environmental amenities (Park space, open spaces and walkable neighborhoods)	Toké, N. A., Boone, C. G., & Arrowsmith, J. R. (2014)
Access to medical facilities	Walker, B. B., Taylor-Noonan, C., Tabbernor, A., McKinnon, T. B., Bal, H., Bradley, D., . . . Clague, J. J. (2014)
Infrastructure dependance	Toke, N. A., Boone, C. G., & Arrowsmith, J. R. (2014)
Walkability	Toké, N. A., Boone, C. G., & Arrowsmith, J. R. (2014)

Table 5. Spatial indicators for socio-economic vulnerability (SEV) assessments.

METHODS	AUTHORS
PCA	Aksha, S. K., Resler, L. M., Juran, L., & Carstensen, L. W. (2020)
	Armaş, I., Toma-Danila, D., Ionescu, R., & Gavriş, A. (2017)
	Maharani, Y. N., Lee, S., & Ki, S. J. (2016)
	Toké, N. A., Boone, C. G., & Arrowsmith, J. R. (2014)
	Alcorn, R., Panter, K. S., & Gorsevski, P. V. (2013)
AHP	Aksha, S. K., Resler, L. M., Juran, L., & Carstensen, L. W. (2020)
	Alizadeh, M., Alizadeh, E., Kotenaee, S. A., Shahabi, H., Pour, A. B., Panahi, M., . . . Saro, L. (2018)
	Armaş, I., Toma-Danila, D., Ionescu, R., & Gavriş, A. (2017)

METHODS	AUTHORS
	Walker, B. B., Taylor-Noonan, C., Tabbernor, A., McKinnon, T. B., Bal, H., Bradley, D., . . . Clague, J. J. (2014)
ANN	Aksha, S. K., Resler, L. M., Juran, L., & Carstensen, L. W. (2020)
	Alizadeh, M., Alizadeh, E., Kotenaee, S. A., Shahabi, H., Pour, A. B., Panahi, M., . . . Saro, L. (2018)
	Maharani, Y. N., Lee, S., & Ki, S. J. (2016)
Dasymetric population mapping	Yuan, H. H., Gao, X. L., & Qi, W. (2019)
	Garcia, R. A. C., Oliveira, S. C., & Zezere, J. L. (2016)
FA	Castro, C. P., Ibarra, I., Lukas, M., Ortiz, J., & Sarmiento, J. P. (2015)
	Zebardast, E. (2013)
MCE	Walker, B. B., Taylor-Noonan, C., Tabbernor, A., McKinnon, T. B., Bal, H., Bradley, D., . . . Clague, J. J. (2014)
	Alcorn, R., Panter, K. S., & Gorsevski, P. V. (2013)
SMCE	Armaş, I., Toma-Danila, D., Ionescu, R., & Gavriş, A. (2017)
	Hizbaron, D. R., Baiquni, M., Sartohadi, J., & Rijanta, R. (2012)
F-ADP	Rezaei-Malek, M., Torabi, S. A., & Tavakkoli-Moghaddam, R. (2019)
OLR	Muir, J. A., Cope, M. R., Angeningsih, L. R., Jackson, J. E., & Brown, R. B. (2019)
Binary Logistic regression	Qasim, S., Qasim, M., Shrestha, R. P., & Khan, A. N. (2018)
Logical analysis method	Chen, Y. (2016)
Distance-based network analysis	Walker, B. B., Taylor-Noonan, C., Tabbernor, A., McKinnon, T. B., Bal, H., Bradley, D., . . . Clague, J. J. (2014)
Overlay analysis	Toké, N. A., Boone, C. G., & Arrowsmith, J. R. (2014)
F'ANP	Zebardast, E. (2013)

Table 6. Methods applied to the spatial assessment of socio-economic vulnerability (SEV).

SPATIAL INDEXES	AUTHORS
SoVI®	Aksha, S. K., Resler, L. M., Juran, L., & Carstensen, L. W. (2020)
	Alcorn, R., Panter, K. S., & Gorsevski, P. V. (2013)
	Zebardast, E. (2013)
Population vulnerability Indexing	Yuan, H. H., Gao, X. L., & Qi, W. (2019)
LA-SoVIC	Toké, N. A., Boone, C. G., & Arrowsmith, J. R. (2014)

Table 7. Spatial indexes for socio-economic vulnerability (SEV) assessments.

METHOD	SOFTWARE	AUTHORS
GIS	ArcGIS	Aksha, S. K., Resler, L. M., Juran, L., & Carstensen, L. W. (2020).
		Yuan, H. H., Gao, X. L., & Qi, W. (2019)
		Alizadeh, M., Alizadeh, E., Kotenaee, S. A., Shahabi, H., Pour, A. B., Panahi, M., . . . Saro, L. (2018)
		Gautam, D. (2017)
		Castro, C. P., Ibarra, I., Lukas, M., Ortiz, J., & Sarmiento, J. P. (2015)
	IDRISI	Alizadeh, M., Alizadeh, E., Kotenaee, S. A., Shahabi, H., Pour, A. B., Panahi, M., . . . Saro, L. (2018)
	ILWIS	Armaş, I., Toma-Danila, D., Ionescu, R., & Gavriş, A. (2017)
	GeoDa Version 16.6	Ley-García, J., Denegri de Dios, F. M., & Ortega Villa, L. M. (2015)
	Not specified	Ponce-Pacheco, A. B., & Novelo-Casanova, D. A. (2018)

METHOD	SOFTWARE	AUTHORS
		Eidsvig, U. M. K., McLean, A., Vangelsten, B. V., Kalsnes, B., Ciurean, R. L., Argyroudis, S., . . . Kaiser, G. (2014)
		Toke, N. A., Boone, C. G., & Arrowsmith, J. R. (2014)
		Walker, B. B., Taylor-Noonan, C., Tabbernor, A., McKinnon, T., Bal, H., Bradley, D., . . . Clague, J. J. (2014)
		Alcorn, R., Panter, K. S., & Gorsevski, P. V. (2013)
		Hizbaron, D. R., Baiquni, M., Sartohadi, J., & Rijanta, R. (2012)
Statistical Analysis	SPSS 22.0	Aksha, S. K., Resler, L. M., Juran, L., & Carstensen, L. W. (2020)
	SPSS 16.0	Qasim, S., Qasim, M., Shrestha, R. P., & Khan, A. N. (2018)
	SPPS	Maharani, Y. N., Lee, S., & Ki, S. J. (2016)
		Castro, C. P., Ibarra, I., Lukas, M., Ortiz, J., & Sarmiento, J. P. (2015)
RS	ENVI	Alizadeh, M., Alizadeh, E., Kotenaee, S. A., Shahabi, H., Pour, A. B., Panahi, M., . . . Saro, L. (2018)
Programming language	MATLAB	Maharani, Y. N., Lee, S., & Ki, S. J. (2016)
Database	Redatam V5.0	Castro, C. P., Ibarra, I., Lukas, M., Ortiz, J., & Sarmiento, J. P. (2015)

Table 8. Tools used for the spatial assessment of socio-economic vulnerability (SEV) assessments.

- The authors further argue that the economic dimension of vulnerability is the predisposition for the loss of economic value (page 2, lines 15/16), which according to my experience is exactly the contrary relationship – also here we do have scholarly articles which did not make it to the current overview. One reason is again the choice of keywords (see below).

  Thanks for the comment. However, while we respect your opinion, based on the previous work of one of the authors, we prefer to stick with the definition of economic dimension of vulnerability formulated by Birkmann et al. (2013 p. 200): 'Economic dimension: propensity for loss of economic value from damage to physical assets and/or disruption of productive capacity'. We consider the opposite concept is more related to economic resilience than vulnerability.

- In the introduction it becomes not clear which specific research question should be answered and were the niche and the gap for the contribution is to be found.
  Thank you for your observation and question. The research question is formulated in the methods section and it is: '(…) what is the state of the art in the spatial assessment of SEV to geohazards in urban environments? (…)'

- Paragraphs addressing common sense are somehow not connected to those showing specific issues; to give an example it remains unclear why paragraph 3 immediately starts with the SoVI as one of the indices available to assess social vulnerability.

  Thanks for this observation. The structure of the paper was modified with the aim to solve this kind of problems. We expect that the comment above does not apply anymore.

- On page 3, line 18 the authors even conclude (or state) that only a few authors have elaborated on the spatial dimension of social vulnerability, which is wrong if proper literature research would have been undertaken. There are lots of studies around on this topic, some of them in the target journal NHESS.

Thanks for this comment. Based on the new search query, we found that the reviewer was totally right, in consequence, we decided to delete this sentence.

- Moreover, the statement that spatial vulnerability assessments only became prominent after the 2004 Indian Ocean Tsunami is neither proven by references, nor true according to my own knowledge.

Thank you for this observation about an incorrectly drafted sentence. Citing Fekete (2012), we wanted to state that events such as the Indian Ocean tsunami in 2004 and Hurricane Katrina in 2005, each with an explicit spatial component, sparked again the research community's interest in those social groups that are more affected by this type of phenomena. We rephrased the sentence accordingly:

'(…) The Indian Ocean tsunami in 2004, as a result of its large impact area, reignited the research community's interest in spatial vulnerability analyses, illuminating the problems faced by low-income population after disasters (Fekete, 2012). This approach was aligned with the Hyogo Framework for Action (UNISDR, 2007), and confirmed by Gautam (2017), who notes that after 2005 a focus on construction and mapping of the SV index intensified. Thus, the use of geographic information systems (GIS) to collect and process data related to hazards and vulnerability was found very suitable (Fekete, 2012). Major earthquakes in the same period as this systematic review (2010-2020), e.g. Chile (2010), New Zealand (2010 and 2011), Nepal (2015), Mexico (2017), Albania (2019), and Croatia (2020) demonstrate the vulnerability of urban areas to seismic damages (Armaş et al., 2017) (…)'.

- Further, the use of GIS is not only very suitable for assessing spatially the issues of social and economic vulnerability, but it is also a tool to exactly do this.

Thank you for this observation about use of GIS. While we agree with your claim, after carefully going through the manuscript, we found that the exact statement in the manuscript is (line 4, page 4): '(…) Thus, the use of geographic information systems (GIS) to collect and process data related to hazards and vulnerability was found very suitable (Fekete, 2012) (…)'. The reason for including this statement is that, in the past, hazard and vulnerability data collection processes were performed manually, making the assessment highly time-consuming. Now, these hazard and vulnerability assessments are speeded up with the integration of GIS into the process. However, the potential of GIS is sometimes untapped and limited to the mapping of the socio-economic characteristics of a case study area, without taking into account the influence of the spatial component that can be integrated to take advantage of the GIS capabilities.

- Finally, the statement that vulnerability is dynamic and subject to spatial and temporal dynamics across scales is not very innovative, there are even specific research papers on this topic from the period 2008-2018.

Thank you for this comment. We agree with the reviewer, in consequence, the statement was deleted.

- Methods: it remains totally open how the amount of 235 papers initially identified was reduced to the final set of 21 contributions.

Thanks for your observation. You can follow the explanation on the text as follows:

'(…)The gross number of articles identified using the search query were 29, having two matching references in Clarivate Analytics and Scopus/Elsevier: Kurnianto et al., (2019) and Eidsvig (2014). Thus, eventually, we identified 27 references. Despite the precise search query, 11 references were discarded due to reasons explained as follows. In chronological order, the first reference discarded was Papathoma-Kohle et al., (2019) because they use variables in the physical dimension, rather than socio-economic one. Two references from Yuan et al., (2019a, b) were identified by the search query as using the same method for the spatial assessment of SEV; so, we decided to select only one of them. Zhang and Huang (2018) address the topic of SV but not its spatial assessment, while Shen et al. (2018) focused on calculating the impact of disasters, rather than estimating SEV. The paper written by Goncalves, M., & Vizintim, M. F. B. (2017) was written in Portuguese, which none of the authors is proficient. Postiglione et al., (2016) promote a culture of seismic risk prevention, rather than to estimate SEV due to earthquakes. Alcántara-Ayala and Oliver-Smith (2014) present the activities undertaken by the ICL Latin -American network (ICL LAB) related to capacity building to reduce risk due to landslides, with no specific emphasis on SEV. Khazai et al., (2014), in their book chapter, concentrate on modelling shelter needs and health impacts caused by earthquakes. Vilches et al. (2014) evaluate the socio-environmental effects of the 27/10/2010 tsunami in Chile, considering the SEV among other aspects, but they do not make use of any spatial variable, indicator, or index, which is similar to the vulnerability assessment relating to a tsunami in the Town of Tirua (Chile) undertaken by Jaque Castillo et al.,(2013). Five references from the previous search query carried out in 2018, and not identified in the refined search query, were included in the list given their relevance due to the geohazards and spatial variables, indicators, and indexes that they address. (…)'.The scheme of the methodology applied is depicted in Figure 1.

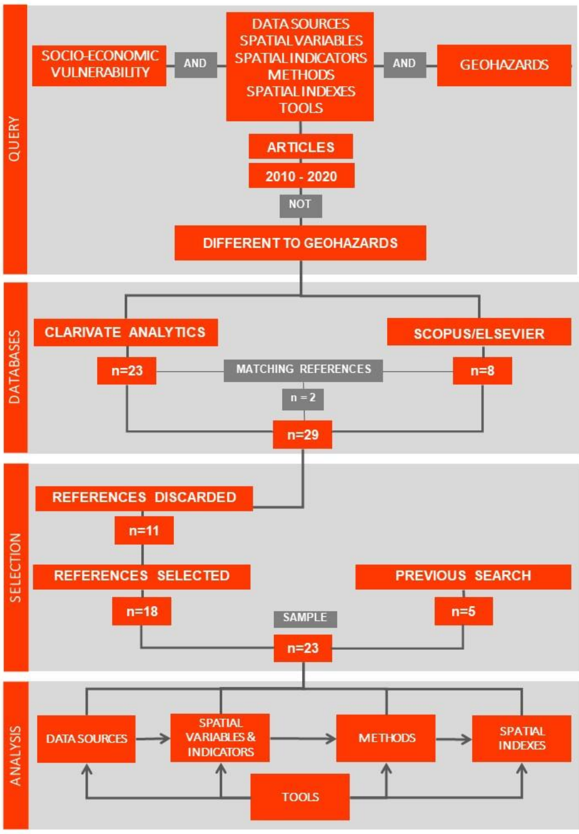

Figure 1. Methodology applied for the systematic literature review

- Moreover, searching only for combinations of "social vulnerability" excludes the amount of (valuable) papers around addressing multiple dimensions of vulnerability – and some of these contributions again can be found in NHESS.

  Thank you for comment. We are aware that apart from the social and economic dimensions, other dimensions of vulnerability also exist such as physical, cultural, environmental and institutional (Birkmann et al., 2013). Nevertheless, we prefer to focus on the social and economic dimensions of the vulnerability for this specific research.

- Further, the authors state in the text that they excluded terms such as "climate change", "health" and "crime analysis", whereas in Figure 1, much more terms have been excluded. BTW: Why has the term "debris" been excluded? Just to give an example, many studies on (social and economic) vulnerability are related to dynamic flooding such as flash floods and debris flows/torrential hazards (even the mentioned EU-funded project MOVE), these are completely ignored by the authors due to their choice of key words.

  Thank you for your comment. We are afraid that the term 'debris' suggested by you is not a spatial variable, indicator or index useful for the assessment of SEV.

- In contrast, some of these hazard types are then mentioned in the results section (page 7, second paragraph).

  Thanks for your observation. In the revised version of the manuscript, we decided to focus sharply on the topic of the spatial assessment of SEV related to geohazards, therefore this comment does not apply anymore.

- Instead of showing which contributions used which methods or indicator groups for assessment, the authors could have shown the challenge of indicator interdependencies, one of the main points of criticism for the SoVI. Simply applying the SoVI does not necessarily result in an overview on social and economic dimensions of vulnerability because of the inherent dependencies between indicators.

  Thank you very much for this suggestion. Nevertheless, the research question of the manuscript is: what is the state of the art in the spatial assessment of SEV to geohazards in urban environments?, rather than discuss the challenge of indicator interdependencies. However, when we discuss the current methods used for the selection of spatial indicators, we are indirectly addressing this topic. Please read the text below as it is written in the manuscript:

  '(…) This systematic review identified the versatility of ANN, which can be either used to extract monthly rainfall data (Aksha et al., 2020), for deriving social vulnerability maps (SVM) (Alizadeh et al., 2018) or to train the self-organized map (SOM) algorithm cluster method (Maharani et al., 2016). The use of dasymetric population mapping not limited to administrative boundaries, even going to block-level to increase the spatial resolution of the population exposure analysis (Garcia et al., 2016) and additionally by including the temporal dimension with its day-night variability, enables improving the accuracy of the spatial assessments of SEV (Yuan et al., 2019a). Factor analysis (FA) is used by Castro et al. (2015) to establish the level of SEV and by Zebardast (2013) to extract primary dimensions and variables of SEV. Alcorn (2013) applied MCE to assess economic vulnerability using four significant factors: population, infrastructure, land use, and economic production. SMCE is applied by Armaş et al., (2017) to integrate social, education, housing, and social dependence vulnerability dimensions and by Hizbaron (2012) to develop deterministic SV scenarios. Zebardast (2013) enters the variables of SEV into a network model in an analytic network process (ANP) to rank the importance of each variable to complete the F'ANP method. This method is focused on developing a composite social vulnerability index (SOVI). Binary logistic regression was the statistical method applied by Qasim et al. (2018) to identify the determinants of landslide risk perception, location being one of them. Walker et al., (2014) present a multi-criteria evaluation (MCE) model that incorporates access to healthcare facilities using GIS to identify and rank residential areas in Victoria, British Columbia. The integration of the concept of uncertainty into ANP using fuzzy numbers (F-ANP) is combined by Rezaei-Malek et al., (2019) with fuzzy DEMATEL (F-DEMATEL) to deal with the interdependency among a set of criteria and fuzzy PROMETHEE II (F- PROMETHEE II) to control the criteria weights, the complete method is denominated fuzzy ANP DEMATEL PROMETHEE II (F-ADP). Ordinal logistic regression (OLR) is used by Muir et al., (2019) to predict the mental health condition of people displaced by series of volcanic eruptions in Merapi, Indonesia, according to their migration status (displaced, moved home, in transition, and moved on), which implies a spatial component. Geological experience and logical analysis method were used by Chen (2016) to select indicators. Toke et al.,(2014) undertake an overlay analysis to identify the census block groups that intersect zones with an extreme ground shaking hazard (…)'.

- In the discussion section the authors have raised some issues that remain questionable, such as the fact that most of the articles related to flood hazard and social vulnerability have been written by geographers because they may be interested in environmental vulnerability.

Thanks for this observation. This statement is not anymore in the revised version of the manuscript since it tackles the spatial assessment of SEV related only to geohazards.

- These issues are just examples underpinning the overall judgement that this contribution is so far not up to international standards. Although the authors have some interesting arguments, I believe that the manuscript needs further improvement to bring it up to an acceptable level before it can be accepted for publication.

Thanks for the assessment of our manuscript. We expect that based on your comments, the comments of the second reviewer and the editor, we have produced a revised version that meets international standards and can, therefore, be published.

- To summarise, it is not clear why the authors chose specific keywords and excluded others, it is not clear why the authors chose the distinct time period between 2008 and 2018 (the discussion on multiple dimensions of vulnerability and the spatiality of vulnerability is much older). The results are not presented in a logical and organised manner, and the conclusions are not underpinned by the results, some of them seem rather driven by speculation than by evidence.

Thank you to you and the reviewers for the detailed assessment of our manuscript. We selected terms and exclude others to answer our research question: what is the state of the art in the spatial assessment of SEV to geohazards in urban environments? which we consider is covered in the period between 2010 and 2020. The aim of this manuscript was not to elaborate on the multiple dimensions of vulnerability, but rather to focus on the social and economic dimensions. We agree that the discussion of the spatiality of vulnerability started long ago and that is why some of the spatial variables were extracted from Meentemeyer (1989). We have restructured our results, and the conclusion section was totally rewritten based on evidence to avoid speculations.

Again, we are most appreciative of the attention and care you have given to our manuscript, and we hope you will now consider it for minor revisions and eventually for publication.

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The spatial dimension in the assessment of urban socio-economic vulnerability related to geohazards, a systematic review

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Abstract. society and the economic dimensions are only two of the dimensions of vulnerability. This paper aims to elucidate the state of the art in data sources, spatial variables, indicators, methods, indexes and tools for the spatial assessment of socio-economic vulnerability (SEV) related to geohazards. The gross number of articles reviewed were 27, from which we identified 18 relevant references using a revised search query, and five relevant references identified using the initial query giving a total sample of 23 references. The most common source of data remains population census. The most recurrent spatial variable used for the assessment of SEV is households without basic services, while critical facilities are the most frequent spatial categories. Traditional methods have been combined with more innovative and complex methods to select and weight spatial indicators and develop indices. The Social Vulnerability Index (SoVI®) remains the benchmark for the assessment of SEV and also as a reference for its spatial assessment. Geographic information systems (GIS), is the most common tool for conducting spatial assessments of SEV regarding geohazards. We recommend considering 3D high-resolution spatial indexes and involving the community in the assessments.

1 Introduction

Vulnerability is defined by the United Nations Office for Disaster Risk Reduction (UNDRR) as 'the characteristics and circumstances of a community, system, or asset that make it susceptible to the damaging effects of a hazard' (Aubrecht et al., 2013). In the past, the vulnerability was

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considered a composite factor having only two dimensions: exposure to risk and susceptibility (Béné, 2009; Chambers, 1989). More recently, Birkmann (2013) considered three factors: exposure, susceptibility and fragility and lack of resilience. The degree of vulnerability a specific community is a human value judgement that highly influences management decisions (McLaughlin et al., 2002). In addition, the concept of social vulnerability (SV) to environmental hazards involves demographic and socio-economic factors that affect community resilience (Zebardast, 2013) and this is considered a hot topic in current disaster research (Shen et al., 2018). The social and economic dimensions are only two dimensions of vulnerability to multiple stressors and shocks. These shocks include include disasters due to the fragility and susceptibility of human well-being, to damaged by disruption to individuals (physical and mental health) and collective social systems (e.g. education, services, health) and their characteristics (e.g., age, ethnicity, disabilities) (Birkmann et al., 2013). Social vulnerability refers to the inability of people, organisations and societies to cope with negative impacts from different stressors to which they are exposed (Eidsvig et al., 2014; Kuhlicke et al., 2011; Myers et al., 2008; Qasim et al., 2018). Typically, this inability results from pre-existing conditions that reduce society's ability to prepare and recover from disasters (Alcorn et al., 2013; Cutter and Finch, 2008; Eidsvig et al., 2014; Zebardast, 2013; Zhou et al., 2014). Social vulnerability additionally identifies sensitive populations that are less prepared to respond, cope with, and recover from a disaster (Zebardast, 2013) such as low-income populations, women, pregnant women, children below 5 years, elderly above 65 years (Zhou et al., 2014) and physically and or mentally challenged individuals (Contreras and Kienberger, 2012). Other vulnerable population groups are low-income population, people with language, cultural and spatial barriers (Eidsvig et al., 2014) such as migrants (Yuan et al., 2019a), rural population, people without post-secondary education and high-density population (Cutter et al., 2003) and are the groups most affected by disasters (Cutter et al., 2003; Eidsvig et al., 2014).

The concept of SV is complex and dynamic, changing through the time and over space, and therefore not easily captured by a single variable (Cutter and Finch, 2008; Zebardast, 2013). It represents the multidimensionality of disasters by focusing attention on the totality of relationships in a given social situation, which, in combination with environmental forces, such as geohazards, results in a disaster (Oliver-Smith, 2003). Social vulnerability attracts less attention by researchers because many challenges are implied in its quantification (Qasim et al., 2018). Power relationships that exclude

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certain individuals or groups from benefiting from disaster risk reduction (DRR) or post-disaster recovery efforts are examples of SV (Contreras et al., 2011). These power relationships manifest between individuals or socio-economic groups in the framework of institutions or culturally determined dialogues about stressors (Warmer et al., 2007).

The economic dimension of vulnerability is the predisposition for the loss of economic value from damage to physical assets (Birkmann et al., 2013) and/or business interruption (activities, services or delivery of products). The assessment of SV is orientated to cast the light on the most susceptible groups of a population to be impacted by a disaster, in the spatial and temporal dimensions (Zhou et al., 2014). Another important aspect to consider is the relationship between social and economic dimensions because, according to Noy (2009), no evidence exists of a correlation between consequences of disasters, such as the number of fatalities or affected population, and GDP growth. Nevertheless, the same author indicates that the degree of damage due to a disaster will negatively influence GDP growth. Thus, Noy (2015) proposes to integrate the number of fatalities and injuries with financial damage due to a disaster using a model similar to the estimation of disability-adjusted life years (DALYs). His index accounts for the number of human years lost as a result of the damage. The spatial dimension of socio-economic vulnerability (SEV) recognises that people and groups of similar characteristics tend to occupy the same or similar areas, while the time dimension of SEV makes reference to people's degree of vulnerability that can change depending on age, life situation, and also season (Wisner and Uitto, 2009). To include urban vulnerability assessment into a spatial plan requires strategic, technical, substantial and procedural integration (Hizbaron et al., 2012). According to Ebert et al., (2009) a spatial indicator of SV is an SV indicator with a physical component. Housing structures and the built environment were previously included by Shuang-Ye, Brent, and Ann (2002) in a GIS-based study of SV. The link between transportation infrastructure and land use had been already studied by Clark et al. (1998). The physical conditions were considered indicative of the social ones by Rashed and Weeks (2003). Kienberger et al.,(2009) proposed a methodology for the spatial quantification of vulnerability and the identification of vulnerability units build upon the geon concept, which is a framework for the clustering of homogeneous spatial information. Khazai et al., (2013) developed a sector-specific vulnerability index (IVIs), which included transport dependency indicators made up by the spatial variables such as freight transport volume

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In the context of disaster risk management and mainly for exposure and impact assessment, the accuracy and reliability of input data are two of the most important factors (Aubrecht et al., 2013). Data constraints plays a key role in the results of the SEV assessment, with the number of variables changing the assessments, and the inclusion of more variables enhancing its precision and enabling the proper presentation of SV assessment (Gautam, 2017). Thus, the the assessment of vulnerability must be done based on indicators and proxy indexes (Qasim et al., 2018) that can guarantee objectivity and can provide quantitative metrics to compare different places (Cerchiello et al., 2018). Indicators and indexes are defined as single qualitative or indirect quantitative measures of a characteristic (Chen, 2016) or a real phenomenon (Fekete, 2009) resulting from systematically observed facts (OECD, 2008). Indicators transform complex data into manageable units of information for performance, change, and achievement assessment (Grace and Edwin, 2009). Indicators also summarise technical information into indexes, simplifying comprehension (Simpson and Katirai, 2006). The most important factor for indicator selection is the availability of data. .The lack of data can lead to reliance on variables that may not be the most accurate indicators of vulnerability (Zhou et al., 2014). Vulnerability indicators are complex measures of a part of what constitutes society or the community. Scientific literature has identified groups of social and economic indicators, which combined with physical and land data are useful for the vulnerability assessment of communities (King, 2001). The use of indicators has primarily been applied to the assessment of adaptive capacity and vulnerability (Chen, 2016).

Indexes are built up based on indicators and later mapped to display the different categories of vulnerability on each administrative zone, limiting the spatial dimension to this stage. The construction of an index implies selection of indicators, indicator normalization and weighting and aggregation into an index (OECD, 2008) that must collectively represent aspects of the society's ability to prepare for, deal with and recover from a disaster (Eidsvig et al., 2014). The most sensitive step for constructing an index is the weighting of indicators. This can be undertaken either using

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participatory approaches such as the analytic hierarchy process (AHP), or the budget allocation process, or statistical assessment like the principal component analysis (PCA), or factor analysis (FA) (Eidsvig et al., 2014; OECD, 2008). Weighting individual indicators is a major challenge for constructing a composite indicator for the vulnerability (Adger et al., 2004; Zebardast, 2013). The objectives of indicators weighting are first, to investigate any correlation among indicators to detect overlapping information and second, to select a suitable weighting and aggregation approach for the final index calculation. Different weightings shows varied spatial vulnerability patterns (Papathoma-Kohle et al., 2019); however, independent of the method applied, after comparing 106 studies for index construction with respect to risk assessment, Beccari (2016) found that the most common approach used (41.5%) was the 'equal weights' method. Eventually, the accuracy of SV assessment lies on the accuracy of input data (Yuan et al., 2019a) and not on the weighting method. After being weighted, indicators can be aggregated using additive, multiplicative, or decision rule models (Eidsvig et al., 2014). The method of aggregation is one of the most pressing problems in developing composite vulnerability indices (Rygel et al., 2006).

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Composite indicators have been commonly employed by researchers, planners, and disaster managers for vulnerability assessments (Yuan et al., 2019a). Cutter, Boruff and Shirley (2003) have constructed an index of SV called (SoVI®) for environmental hazards in the United States using a factor analytic approach computed in a summary score based on an additive model. In the framework of the Methods for the Improvement of Vulnerability Assessment in Europe (MOVE) project, variables were grouped into single (Vinchon et al., 2011) and composite indicators. In the case study area of Salzburg, an expert-based approach was chosen, and several experts were asked to allocate weights according to the contribution of each variables to the vulnerability of floods (Contreras and Kienberger, 2011). Other composite indicators useful for the vulnerability assessment are the Prevalent Vulnerability Index (Cardona, 2005), Environmental Sustainability Index (Esty et al., 2005) and Human Development Index (UNDP, 2010). All these indexes face challenges when assessing vulnerability indicators, such as: ranking socio-economic data on an interval scale, dealing with temporal aspects (day-night changes), choosing the most suitable data resolution to avoid the 'modifiable areas unit problem' (MAUP) (Openshaw, 1983), deciding how to allocate a meaningful value to socio-economic variables, and how these aspects together affect the vulnerability

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assessment of each case study areas (McLaughlin et al., 2002). The compilation of all of the SV indicators used through time was undertaken by Fatemi, Ardalan, Aguirre, Mansouri and Mohammadfam (2017); however, they neither included the spatial dimension in their systematic review nor focused exclusively on geohazard as in this research.

Quantitative measures to develop indicators can be spatially explicit and based on spatial variables, such as location, area, range, distance, direction, spatial geometries, and patterns (Unwin, 1996), spatial connectivity, mobility (Béné, 2009), isolation, diffusion, distribution, spatial association, spatial interaction, spatial evolution, spatial synthesis and scale of the affected area and surroundings (Béné, 2009; Buzai and Villerías Alarcón, 2018; Contreras et al., 2013; Meentemeyer, 1989). The geographic patterns in vulnerability can increase due to spatial interactions; while additional patterns within these components may be related to the nature of vulnerability stemming from a specific hazard (Amram et al., 2011). The main aim of this research is to elucidate the state of the art in data sources, spatial variables, indicators, methods and indexes and tools for the assessment of the SEV related to geohazards in urban environments. Geohazards can be internal such as earthquakes, tsunamis, and volcanic eruptions and external such as landslides, soil erosion, and land degradation. We particularly focus on these phenomena for two reasons: first, geohazards are the natural phenomena that have produced the highest quantity of losses in recent years in the urban environments in Chile, and, second, because geohazards are the phenomena addressed by the institutions involved in the present research.

The Indian Ocean tsunami in 2004, as a result of its large impact area, reignited the research community's interest in spatial vulnerability analyses, illuminating the problems faced by low-income population after disasters (Fekete, 2012). This approach was aligned with the Hyogo Framework for Action (UNISDR, 2007) and confirmed by Gautam (2017) who notes that after 2005 there has been an intensive focus on construction and mapping of the SV index. Thus, the use of geographic information systems (GIS) to collect and process data related to hazards and vulnerability was found very suitable (Fekete, 2012). Major earthquakes in the same period as this systematic review (2010-2020), e.g. Chile (2010), New

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Zealand (2010 and 2011), Nepal (2015), Mexico (2017), Albania (2019) and Croatia (2020) demonstrate the vulnerability of urban areas to seismic damages (Armaş et al., 2017).

This research reviews case study areas, data sources, spatial variables, indicators, methods, indexes and tools used in the spatial assessment of SEV vulnerability by different authors in the period between 2010 and 2020. This systematic review aims to evaluate the literature to identify patterns and trends, as well as research gaps, to recommend new research areas through an overview paper. This article aspires to be a guide for scientists who want to perform any spatial assessment of SEV vulnerability. Socio-economic vulnerability is dynamic and changes across spatial and temporal scales, depending on demographic, geographic, economic and cultural factors. Hence, no one-size-fits-all approach exists to measure and reduce SV (Zhou et al., 2014). This paper is divided into six sections. The introduction is the first section and includes a literature review. The second section, on methods, elaborates on the criteria for selecting the articles that comprise the systematic review and the format of the presentation of results. The third section focuses on the results. The fourth section includes the discussion of the results supported by literature, and the fifth section contains conclusions with recommendations proposed in the sixth section.

2 Methods

A systematic review searches for, appraises, and synthesises research evidence (Grant and Booth, 2009). In the present research, the systematic review was conducted to elucidate the state of the art of data sources, spatial variables, indicators, methods, indexes and tools for the spatial assessment of the SEV related to geohazards, which we consider is covered in the period between 2010 and 2020. Thus, the main research question is: what is the state of the art in the spatial assessment of SEV to geohazards in urban environments?

This review was conducted in December 2018 and re-run during the revision process in March 2020. For this research, Clarivate Analytics and Scopus/Elsevier were the sources of selected literature given their functionalities to run the search query. We limited the query to articles published

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in academic journals because they typically are more rigorous in the methodology and therefore contain more complete and consistent results. The terms selected for the search query refer to vulnerability in the socio-economic dimension, the spatial variables listed by nwim Meentemeyer (1989), Béné (2009), Contreras et al. (2013) and Buzai and Villerías Alarcón (2018) and the aforementioned external and internal geohazards. Based on several screenings, to refine the search strategy, we opted to exclude terms that were not related to geohazards and were recurring in the titles, abstracts and keywords of the resulting references. The final set of terms included and excluded in the search query are listed in Table 1 and the scheme of the methodology applied is depicted in Figure 1.

Table 1 about here

Fig. 1 about here

The findings will be presented in the resulst section in tables related to selected references selected, data sources, spatial variables, indicators, methods, spatial indexes, and tools. Table 2 is structured in four columns, namely author, year, research objective, geohazard addressed and country where the case study area of the paper is located. The authors are listed from the most recent reference to the oldest one. Tables 3, 4, 5, 6 and 7 are structured mainly in two columns: the first column lists data sources, spatial variables, indicators, methods and indexes respectively. The second column contains the authors and the year of their publications, in which the mentioned topics are addressed. Moreover, the references in these tables are also listed in reverse chronological order. Table 7 includes three columns, namely, method, software and authors.

3 Results

The gross number of articles identified using the search query were 29, having two matching references in Clarivate Analytics and Scopus/Elsevier: Kurnianto et al., (2019) and Eidsvig (2014). Thus, eventually, we identified 27 references. Despite the precise search query, 11 references were discarded due to reasons explained as follows. In chronological order, the first reference discarded was Papathoma-Kohle et al., (2019) because

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they use variables in the physical dimension, rather than socio-economic one. Two references from Yuan et al., (2019a, b) were identified by the search query as providing the same method for the spatial assessment of SEV, so, we decided to select only one of them. Zhang and Huang (2018) address the topic of SV but not its spatial assessment, , while Shen et al. (2018) focused on calculating the impact of disasters, rather than estimating SEV. The paper written by Goncalves, M., & Vizintim, M. F. B. (2017) was written in Portuguese, which none of the authors is proficient in. Postiglione et al., (2016) promote a culture of seismic risk prevention, rather than to estimate SEV due to earthquakes. Alcántara-Ayala and Oliver-Smith (2014) present the activities undertaken by the ICL Latin -American network (ICL LAB) related to capacity building to reduce risk due to landslides, with no specific emphasis on SEV. Khazai et al., (2014) on their book chapter concentrate on modelling shelter needs and health impacts caused by earthquakes. Vilches et al. (2014) evaluate the socio-environmental effects of the 27/10/2010 tsunami in Chile considering the SEV among other aspects but they do not make use of any spatial variable, indicator, or index, which is similar to the vulnerability assessment relating to a tsunami in the Town of Tirua (Chile) undertaken by Jaque Castillo et al.,(2013). Five references from the previous search query carried out in 2018 and not identified in the refined search query were included in the list given their relevance due to the geohazards and spatial variables, indicators and indexes that they address. The 23 references finally reviewed are listed in Table 2.

Table 2 about here

The most recurrent geohazards addressed among the selected papers are earthquakes, followed by landslides, volcanic eruptions, tsunami, and subsidence, detailed information about the number of literature references that tackle each hazard is depicted in Figure 2. None of the references deals with soil erosion, nor land degradation. Case study areas selected from this set of papers are frequently located in Indonesia, China, Iran, and the USA,detailed information about the number of literature references that has case study areas on these countries can be appreciated in Figure 3.

From the set of selected papers, the most common sources of data are the population census, followed by satellite images, field observations, disaster

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databases, surveys, aerial photographs, and land use and land cover (LULC) maps. Other authors used landslide susceptibility maps, orthophotos, and volunteered geographic information (VGI). The complete set of data sources identified in this systematic review are listed in Table 3.

Figure 2 about here

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Table 3 about here

The most common spatial variables used for the spatial assessment of SEV between 2010 and 2020 are households without basic services (piped water connection, electricity, sewerage infrastructure, cell phone, or landline), location, critical facilities (fire stations, medical emergency services, medical facilities, and hospitals), distance from faults/causative faults, precarious housing (low quality and/or precarious external walls, roofing, and floors), the total area of occupied space in the residences, and the presence of schools. The complete set of spatial variables identified in this systematic review are listed in Table 4.

Table 4 about here

Population density, housing density, hospital beds per 1,000 people, and living space per person are the most frequent spatial indicators of SEV. Global Moran's I and local indicators of spatial association (LISA), which are traditional indicators in the spatial assessment were also identified in this systematic research. We also found indicators such the access to environmental amenities and medical facilities, basic census units (BCU) target zones, and population, employed/unemployed density, floating population, and literate people density among others. The complete set of spatial indicators identified in this systematic review are listed in Table 5.

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Results extracted from the literature indicate that that the most common methods in the last 10 years for the reduction of variables is principal component analysis (PCA) and for indicators weighting is Analytic Hierarchy Process (AHP). The use of artificial neural networks (ANN) has been gaining ground in the last 10 years as a method for the assessment of SEV. Other methods include dasymetric population mapping, factor analysis (FA), ordinal logistic regression (OLR), spatial multi-criteria evaluation (SMCE) and analytic network process (ANP). We also found also hybrid methods that combine FA and ANP known as F'ANP, and others that combine fuzzy numbers with ANP, DEMATEL and PROMETHEE II (F-ADP). Other methods were simpler, such as an overlay analysis. The complete set of methods used by authors and identified in this systematic review is listed in Table 6.

Table 6 about here

The Social Vulnerability Index (SoVI®) remains the benchmark for the assessment of SEV and a reference for its spatial assessment. The complete set of spatial indexes used by authors and identified in this systematic review is listed in Table 7.

Table 7 about here

The tools to carry out the spatial assessment of SEV were selected according to the identified spatial variable and indicators, the method used, and the indexes used, adapted, or developed. The most frequent tool for the spatial assessment of SEV is GIS, followed by statistical analyses undertaken in the statistical package for the social sciences (SPSS), remote sensing (RS) using the environment for visualizing images (ENVI), programming languages and interactive databases such as the retrieval of data for small Areas by microcomputer (REDATAM) (CELADE, 2015). The complete list of tools used by the authors selected is found in Table 8.

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4 Discussion

For the purpose of the systematic review, we found that the Clarivate Analytics database identified more accurately the references for this systematic review, and it is more user-friendly, than other databases. The lack of articles that tackle external geohazards can be explained by the fact that we excluded from the search query words such as “climate change” OR “ecological” OR “drought”, which are indirectly related to these phenomena. Nevertheless, considering that these geohazards usually takes place in rural, rather than urban environments, they are not relevant for this research.

The case study areas of the selected papers confirm the finding from Shen et al., (2018) relating to the USA, China, and Iran as major contributors to disasters research together with Italy, Indonesia, Germany, Turkey, England, India and Spain in the topics of ‘prediction model’, ‘social vulnerability’ and ‘landslide inventory map’. Nevertheless, the references that use Indonesia as a case study area are focused on earthquakes and volcanic eruptions, not necessarily on the tsunami hazard as it was also suggested by Shen et al., (2018).

The research concentrated on the local level uses primary data collected via field observations, questionnaire surveys or focus groups with representative members of the community to assess vulnerability (Birkmann, 2006; Khazai et al., 2017; Sarkar and Vogt, 2015), while for global or regional scales, primary data is derived from satellite images, aerial Photograph, LULC, landslide susceptibility maps, orthophotos, or VGI are used. Secondary data is obtained from the population census, disaster databases and population datasets. For applications on the regional, national, international or worldwide scale, coarse-scale raster data on population patterns are appropriate, but for city or local scales, representation of higher spatial resolution is requested, such as fine-scale population grids which finally go to individual building level (Aubrecht et al., 2013). Census data usually presents national data at the municipal level. Census and land databases are highly demanded by planners and disaster managers. However, there are several problems associated with using large community databases, such as scale, data decay, relevance (King, 2001), and time-constrains.

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Current data can easily change with the building of a new road or new houses (McLaughlin et al., 2002) and in the case of nomadic and/or geographically isolated groups, these data sets are rarely available (Béné, 2009) but they are necessary. Censuses are usually updated on an average of ten years, depending on the country, and some of the data could be altered by political biases. The surveys require significant resources, and the thematic scope is usually very narrow. These disadvantages can explain the strong demand for population data, independent of administrative areas, making it sometimes necessary to extract data from raster representations or using dasymetric mapping (Aubrecht et al., 2013; Garcia et al., 2016; Yuan et al., 2019a). Currently, data in 3D can be also extracted from VGI, which is an alternative source of real-time information based on the concept of citizens as sensors (Cervone and Hultquist, 2018).

Satellite images are useful to collect data from global to local scales. Rapid mapping concepts are mainly applied in structural post-disaster damage assessment, relaying on earth observation data from different sensors, sometimes provided by the International Charter Space and Major Disasters (2020) (Aubrecht et al., 2013). Lidar data are a good option for the city scale. The use of satellite images as data sources in the spatial assessment of SEV has been increasing in the last ten years, which can be explained because they offer quick, updated, and reliable data, making the satellite images currently the most effective source of information to date. One of the issues with using maps, air photos, or orthophotos as a resource is that they are not frequently updated.

The spatial variables found through this systematic review are similar to the variables identified by Meentemeyer (1989), Béné, (2009) Contreras et al. (2013), Buzai and Villerías Alarcón (2018). Based on the concept of spatial indicator of SV formulated by Ebert et al., (2009), we consider the lack of basic services as a spatial variable of SEV because all these networks are distributed in a specific spatial area in the spatial dimension. The lack of life-supporting infrastructure and/or infrastructure necessary for the functioning of the society such as piped water connection, electricity networks, sewerage infrastructure, telecommunications and road networks hampers emergency management and therefore the recovery process

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(Eidsvig et al., 2014). Housing quality and tenancy conditions describes the vulnerability of the population to become homeless after a disaster (Toke et al., 2014). Housing type is an economic indicator of the economic status of individuals, communities, and nations. Thus, a house with low quality or precarious external walls located in a landslide-prone zone is usually associated with socially vulnerable communities having a negative influence on the quality of life. However, the typology of vulnerable houses depends also on the sort of landslide (Eidsvig et al., 2014). There are similar spatial variables used to produce an indicator of housing overcrowding (Ponce-Pacheco and Novelo-Casanova, 2018) such as households per housing unit (Zebardast, 2013) and Households with >1 family (Aksha et al., 2020). We argue that besides spatial variables, we must also consider spatial categories in which critical and the other urban facilities must be included. These facilities are not only providers of services but are also sources of employment (Contreras et al., 2017); therefore their presence or absence, access to, distance, travel time (Toke et al., 2014) and/or barriers (Walker et al., 2014) to reaching them highly influence the degree of spatial SEV of a community. We also identify other spatial variables that are different to more traditional ones such as distance from faults (Hizbaron et al., 2012; Rezaei-Malek et al., 2019) and volcanoes (Kurnianto et al., 2019), land use (Alcorn et al., 2013), city blocks (Yuan et al., 2019a) and displacement (Muir et al., 2019) among others.

Based on the evidence found by this research, we agree with Zeng et al. (2012) that the most frequent spatial indicator in the assessment of SEV related to geohazards is population density, and it has the highest sensitivity coefficient (Yuan et al., 2019a). According to Kurnianto et al. (2019), high population density is the factor that contributes most to the high SV, and it is usually linked to high population growth, which increases the SEV given the rise in the exposure of population and business. The reason, according to Gu et al. (2018), is that population density reveals the human resources of a neighbourhood and the relief resources that could be required during a disaster. This is a key factor in large case study areas where different kinds of occupation can take place (urban, rural), therefore important differences in population density are expected to be found. Disadvantaged population tends to live in denser neighbourhoods with more crowded parks and other recreational facilities (Sister et al., 2009; Toke et al., 2014; Wolch et al., 2005) and low levels of walkability (Bereitschaft, 2017b) that exacerbate their vulnerability making an evacuation difficult (Cutter et al., 2003) after an earthquake, tsunami, volcanic eruption, or landslide. It is also more difficult in such areas to find spaces to

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install temporary shelters near to their households or areas providing care after an emergency (Cutter et al., 2003). The density of the built environment is especially important in the case of seismic events (Toke et al., 2014). Innovative spatial indicators such as employed density, unemployed density, and literacy people density were proposed by Alizadeh et al. (2018). The importance of such fine-scale data and the temporal variations (daytime and night-time) for accurately estimating SV was highlighted by Yuan et al., (2019a) proposing the indicator: 'floating population'. The consideration of the spatial and temporal dimension in the estimation of population exposure is a fundamental aspect of accurate catastrophe loss modelling, a key element for the integration of risk analysis and emergency management (Aubrecht et al., 2010), and therefore for the reduction of the SEV (Alizadeh et al., 2018). Chen (2016) proposes more spatial indicators in the economic rather than social dimension. Ley-García et al. (2015), global Moran's I and LISA enable the identification of dependence between attributes and localisations. As a result, these indicators are useful to determine whether the spatial distribution of elements influences the behaviour of a particular variable. The summary measure of autocorrelation in the territory is undertaken with global Moran's I, while the autocorrelation of the spatial units included in the territory is measured using LISA. Cutter and Finch (2008) also previously utilised global Moran's I and LISA to identify local variability and cluster similarity of low and SV. Besides the SoVI® and FA, Zhou et al. (2014) utilise exploratory spatial data analysis (ESDA) to identify the spatio-temporal patterns of SV based on the constructed SoVI® for each county in China. These authors used global and local Moran's I or LISA as ESDA to determine the spatial autocorrelation amongst counties and identify the similarity and/or dissimilarity in the clustering of SV.

Accessibility as spatial indicator is defined as the ability for contact and interaction with places of economic or social opportunities (Deichmann, 1997). Goodall (1987) notes that accessibility is the ease to reach a location from another location and this concept is related again to the opportunities for contact, interaction, and attention (Aubrecht et al., 2013) in the case of , for example, hospitals and/or trauma centres, that accessibility is reduced by distance (Hizbaron et al., 2012; Zeng et al., 2012). Besides the common spatial variables, indicators and indexes in 2D, there are also spatial indicators and indexes that include a 3D component, such as Walk Score®, neighbourhood walkability (Bereitschaft, 2017a, b), satisfaction with the neighbourhood (Barata et al., 2011), and residential condition (de la Torre and de Riccitelli, 2017) that could be applied to

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the spatial assessment of SEV. Authors such as Yuan et al (2020), and Muir et al (2019) consider the spatial indicators of mobility and migration respectively in the framework of geohazards, being migration a topic mainly addressed by authors in the climate change community e.g. Nakayama et al.,(2019), Naugle et al.,(2019), Locke,(2009) and so forth.

This systematic review identified the versatility of ANN, which can be either used to extract monthly rainfall data (Aksha et al., 2020) or for deriving social vulnerability maps (SVM) (Alizadeh et al., 2018) or to train the self-organized map (SOM) algorithm cluster method (Maharani et al., 2016). The use of dasymetric population mapping not limited to administrative boundaries, even going to block-level to increase the spatial resolution of the population exposure analysis (Garcia et al., 2016) and additionally by including the temporal dimension with its day-night variability, enables improving the accuracy of the spatial assessments of SEV (Yuan et al., 2019a). Factor analysis (FA) is used by Castro et al. (2015) to establish the level of SEV and by Zebardast (2013) to extract primary dimensions and variables of SEV. Alcorn (2013) applied MCE to assess economic vulnerability using four significant factors: population, infrastructure, land use and economic production. SMCE is applied by Armaș et al., (2017) to integrate social, education, housing, and social dependence vulnerability dimensions and by Hizbaron (2012) to develop deterministic SV scenarios. Zebardast (2013) enters the variables of SEV into a network model in an analytic network process (ANP) to rank the importance of each variable, to complete the F'ANP method. This method is focused on developing a composite social vulnerability index (SOVI). Binary logistic regression was the statistical method applied by Qasim et al. (2018) to identify the determinants of landslide risk perception, being location one of them. Walker et al., (2014) present a multi-criteria evaluation (MCE) model that incorporates access to healthcare facilities using GIS to identify and rank residential areas in Victoria, British Columbia. The integration of the concept of uncertainty into ANP using fuzzy numbers (F-ANP) is combined by Rezaei-Malek et al., (2019) with fuzzy DEMATEL (F-DEMATEL) to deal with the interdependency among a set of criteria and fuzzy PROMETHEE II (F- PROMETHEE II) to control the criteria weights, the complete method is denominated fuzzy ANP DEMATEL PROMETHEE II (F-ADP). OLR is used by Muir et al., (2019) to predict the mental health condition of people displaced by series of volcanic eruptions in Merapi, Indonesia, according to their migration status (displaced, moved home, in transition, and moved on), which implies

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a spatial component. Geological experience and logical analysis method were used by Chen (2016) to select indicators. Toke et al. (2014) undertake an overlay analysis to identify the census block groups that intersect zones with an extreme ground shaking hazard.

Aksha et al., (2020) utilized the SoVI® to map the vulnerability levels in the study site with a multi-hazard map to produce a total risk map. Alcorn et al. (2013) used an improved version of the same index, but specifically adapted it to the variability in SEV in the case study area that was focused on census-designated places (CDPs) on a small scale. The population vulnerability indexing developed by Yuan et al., (2019a) considered the most of the indicators available in the literature already identified by the SoVI®, but they adapted their index to the Chinese society, where according to the authors, race and ethnicity are not relevant indicators and rural-to-urban migrants are floating population with unequal access to public services and therefore a vulnerable population. Toké et al (2014), build upon the SoVI® to create their own SV indexes that incorporate the spatial dimension. According to the LA-SoVIC developed by Toket et al. (2014) SV is highly linked to the normalised difference vegetation index (NDVI) as a proxy for urban green space. Green areas are usually located in areas with lower SEV (Stow et al., 2007), and have also been recognised for their health benefits (Bedimo-Rung et al., 2005). Physical characteristics of green areas, such as attractive scenery, motivates people to stay and visit an area (Kurnianto et al., 2019), resulting in increased the social control and reduced SEV.

It has been always difficult to quantify SV; hence, it is absent from post-disaster cost/loss estimation reports (Schmidtlein et al., 2008; Zhou et al., 2014). The use of spatial variables, indicators, and indexes will bridge the gap of integrating physical vulnerability and SV to achieve a holistic risk assessment. Davidson (1997) provides the first attempt to create an integrated risk assessment framework. Later, Carreño, Cardona, & Barbat, (2007) developed a risk index obtained by multiplying the physical risk index by an impact factor, which is, in fact, an aggravating coefficient consisting of socio-economic variables; nevertheless, in applying this method, the outcome will be similar to the assessment of physical vulnerability, without showing the contribution of SV to the assessment of integrated risk. Schmidtlein, Shafer, Berry and Cutter (2011) tested the link between SV and earthquake losses. The authors found that physical parameters related to hazard, such as distance from the epicentre and peak ground acceleration, were more significant in predicting impacts than was SV. Nevertheless, the same authors established that SV is a significant

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predictor of earthquake losses when accounting for wealth (dollar losses per average income as the dependent variable). The previous finding reveals that those areas with higher levels of SV experience a greater relative impact than areas with lower degrees of SV.

Geospatial information systems are broadly utilised by several authors to collect and process data and map the SEV. GIS has been enabling researchers to have either large study regions, or equivalently, data sets at much finer spatial resolution (Unwin, 1996), for example, a comprehensive overview of the use of accessibility indicators in GIS was already provided by Deichmann (1997). Each author uses different versions of ArcGIS, which is the most widespread software used in GIS. The IDRISI software is utilised by Alizadeh et al. (2018) to generate a Social Vulnerability Map (SVM). Armaş et al., (2017) applied a pairwise comparative method in the AHP implemented in the SMCE module of the Integrated Land and Water Information System (Ilwis) software. GeoDa, an open-source software focused on methods for spatial data, and has been used by authors who address the topic of spatial association (Gu et al., 2018; Ley-García et al., 2015). The aforementioned is an RS and GIS software, on which the robustness of the results from Armaş et al. (2017) was also tested, with a sensitivity analysis performed in the DEFINITE toolbox implemented in IlWIS. The MATLAB computation environment was used by Maharani et al. (2016) to develop the SOM toolbox. Sherly et al. (2015) also use MATLAB to perform multivariate data analyses, such as PCA and Data Envelopment Analysis (DEA). REDATAM used as a source of data by Castro et al., (2015), is an interactive hierarchical database that contains microdata and/or aggregate socio-economic information from any geographical division at a national level. This database combines data from the census, surveys and other sources, resulting in a very comprehensive and useful source of spatial and not-spatial variables for the SEV.

5 Conclusions

Based on the evidence, we can state that the most of the spatial assessments of SEV in urban environments have been done for earthquakes and landslides and that Indonesia, China, Iran and the USA lead the research in spatial assessment of SEV related to geohazards in urban environments. The scale of the spatial level of assessment – namely, global, continental, subcontinental, national, regional, provincial, municipal, or local –

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determines the type of data to be collected and the assessment approaches. Although there have been advances, the census data continues to be the most frequent source of data for the SEV assessments; however, in the cases of spatial assessment the satellite images are now the main data source, facilitating the inclusion of the spatial component in SEV assessments. The spatial assessment of SEV allows visualising and communicating, social phenomena and components that influence the degree of vulnerability that is not visible with other methods. The lack of data availability hinders the understanding of the concept of vulnerability (Zhou et al., 2014) and that is why VGI is essential today to obtain updated information in real-time, at local scale, when other data sources are not available.

Traditional spatial variables and indicators continue to be used by authors, but, combined with new variables, categories, and indicators, including the temporal dimension (day-night), and assessing at the local level, can increase the accuracy of spatial assessments of SEV and reduce uncertainty on their assessment. Each method for the spatial assessment of SV is selected according to the research aim, case study area, scale to cover, reliability of data sources, spatial variables and indicators available; geohazard to address, the scope of the research, and the level of funding. Methods such as ANN are gaining ground in the assessment of SEV. Other methods such as dasymetric population mapping enable making more accurate SEV assessment. Factor analysis continues to be a useful tool to define the level of SEV based on primary dimensions and variables. Multi-criteria evaluation method offers a robust decision-making technique based on flexible choice and combination in criteria (Alcorn et al., 2013). SMCE incorporates the spatial component to the MCE to integrate spatial and non-spatial data to generate maps with multiple scenarios (Hizbaron et al., 2012). Classic methods such as FA are combined with more innovative ones such as ANP and fuzzy numbers to generate hybrid methods such as F'ANP. These new methods encourage the development of more complex hybrid methods such as F-ADP that increase the accuracy and reduce the uncertainty levels in the spatial SEV assessments. Ordinal logistic regression and binary logistic regression are useful methods to identify spatial variables as determinants of SEV. The spatial component can be also be added by simply overlapping the areas with hight SEV with hazard zones using GIS. Most of the authors have built upon the SoVI® developed by Cutter et al. (2003) to quantify SEV or to create their own SEV indexes, demonstrating that it remains as the benchmark for the assessment of SEV and a reference for its spatial assessment.

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Geographic Information Systems, statistical analysis, RS, programming languages, and interactive databases are the tools currently used by the scientists for the assessment of SEV vulnerability. The spatial assessment of SEV in the areas where it is requested must depend not only on the financial resources for research but also on the availability of opensource software with the functionalities of spatial statistics, such as QGIS, GeoDa or Ilwis. Authors combines traditional and new data sources, spatial variables and indicators, methods, indexes and tools including the temporal dimension, increasing the resolution to the local level with the aim to increase the accuracy and reduce the uncertainty of spatial assessments of SEV related to geohazard in urban environments.

6 Recommendations

The development of a global spatial index of SEV is an urgent task, with the aim of making informed decisions about priority in funding prevention and mitigation actions related to geohazards in urban environments. In the meantime, the priority for these types of assessments must be allocated to developing countries with the lowest GDPs and increased levels of SV (Zhou et al., 2014). More spatial assessment of SEV due to volcanic eruptions and tsunamis are in the urban environments are needed, but also due to soil erosion and land degradation in the rural zones. Furthermore, the priority must be to allocate funding for these countries with high SEV to enable the update of their census information, as this is the most frequent source of secondary data for any SEV assessment. It is also important to encourage the population to share information through social media (SM) about the vulnerable conditions in which they live, putting in practice the concept of citizen as a sensor (Cervone and Hultquist, 2018).

An assessment of SEV is a condition for the effective development of emergency management capabilities and to reduce the overall time for social recovery after an earthquake (Aubrecht et al., 2013; Garcia et al., 2016). Likewise, spatial assessments of SEV must be considered before taking resettlement decisions for not creating again spatial conditions that favours the SEV. Authors such as Turvey (2007), Walker et al. (2014), Zhou et

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al. (2014) and Gautam (2017) highlight the need for place-specific, sub-provincial-level, neighbourhood-scale, or local level vulnerability indexes, due to geographic variations in population composition and social structures (Bell N et al., 2007). The macro-scale socio-economic assessment identifies general patterns but fails to capture the detail of the heterogeneity at the micro-scale. Thus, assessment at the provincial, county or state level can result in lost information (Zhou et al., 2014) or requires tackling issues such as ecological fallacy or MAUP (McLaughlin et al., 2002; Openshaw, 1983; Pacione, 2005). In the spatial assessment of SEV, it is necessary to go beyond the administrative boundaries or cartographic variables, with methods such as the dasymetric population mapping (Garcia et al., 2016; Yuan et al., 2019a), square mesh (Renard, 2017), pockets (Lin and Hung, 2016), or *geon* (Kienberger et al., 2009). We found interesting spatial indicators of SEV, such as population density based on land use (Zeng et al., 2012), which we consider more accurate than population density estimated at an area unit. This indicator can better integrate, using RS, the spatial dimension of the exposure and susceptibility of the population in the assessment of the SEV of a case study area. To improve the accuracy and reduce the uncertainty in spatial assessments of SEV must always be the aim. The presence of urban facilities must be included in the assessment of SV. Walker et al. (2014) suggest developing a weighted 'local resource' index for assessing systemic vulnerability since, for example, the absence of sports facilities is associated by Iguacel et al. (2018), Vandermeerschen, Vos, & Scheerder (2015), and Aguilar-Palacio, Gil-Lacruz and Gil-Lacruz (2013) with high levels of SV. In the spatial assessment of SEV, it is necessary as well to consider the influence of the spatial component represented by physical space in the degree of vulnerability of a specific area, such as the relationship between slums and a low degree of wellness and health (Buzai and Villerías Alarcón, 2018).

It is necessary to take advantage of the versatility of methods such as ANN based on machine learning to make progress in the spatial assessment of SEV and SMCE in order to map multiple scenarios to inform urban communities and to integrate them in the decision making processes. Communities respond differently to vulnerability maps depending on the purpose behind the maps or their cultural background of the community. . On the one hand, some communities reject being mapped as 'victims', but on the other hand, some request being identified as highly vulnerable to gain access to funding opportunities for activities of risk management (Fekete, 2012). The Walk Score® index developed by Bereitschaft (2017a)

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although originally orientated to measure only neighbourhood walkability (Bereitschaft, 2017b), could be adapted as a tool to either complement or validate any spatial index for assessing SEV at the local level. The advantage over the SoVI® is that while the SoVI® can be spatialised, Walk Score® is a 3D high resolution spatial index *per se*. The use of the local scale for the assessment of SV will be more useful for the planning of resilient actions (Lee, 2014; Maharani et al., 2016) than would be vulnerability assessment at a regional scale, which is more orientated to the collection of pathologies in the social dimension. It is necessary to more closely examine so-called 'proxy indicators' to measure SV at micro-local scales or intra-city levels (Gu et al., 2018). The right management of the spatial component by a community can reduce its economic vulnerability. Groß (2017) presented the case of ski-lift entrepreneurs in Vorarlberg (Austria) who reduced the probability of business interruption by accelerating the uphill and downhill flows of people through manipulating snow and topography. Regarding tools, it is necessary to take full advantage of the functionalities of opensource software such as and QGIS and ILWIS to make the spatial assessment of SEV to the reach of all the scientific communities around the world.

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