Review Article: A Comparison of Flood and Earthquake Vulnerability Assessment Indicators

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General comments

We would like to thank the reviewers for their very valuable comments. We acknowledge the fact that we were not clear enough in defining the scope of our paper and in particular our usage of a narrow definition of vulnerability and the focus on single-hazard type risk assessment models. We recognize that this may have caused confusion and therefore we have made the following general changes:

- *We included a more explicit explanation of the scope of our paper: to conduct a literature review comparing methods for quantitatively assessing vulnerability in flood and earthquake risk assessments within which we look at both physical and social vulnerability aspects.*
- *Therefore, we have increased the depth of our analyses by adding 22 citations to support our statements and to bring more balance in the physical and social aspects of vulnerability in risk models. We included references suggested by the reviewers, such as:*
    - *Alexander, D. (1997). The study of natural disasters, 1977–97: Some reflections on a changing field of knowledge. Disasters, 21(4), 284-304.*
    - *Tate, E. (2012). Social vulnerability indices: a comparative assessment using uncertainty and sensitivity analysis. Natural Hazards, 63(2), 325-347.*
    - *de Sherbinin, A., & Bardy, G. (2015). Social vulnerability to floods in two coastal megacities: New York City and Mumbai. Vienna Yearbook of Population Research, 131-165.*
    - *Cardona, O. D. (2004). The need for rethinking the concepts of vulnerability and risk from a holistic perspective: a necessary review and criticism for effective risk management. Mapping vulnerability: Disasters, development and people, 17.*
    - *Cardona, O. D., & Carreño, M. L. (2011). Updating the indicators of disaster risk and risk management for the Americas. IDRIM Journal, 1(1), 27-47.*
- *We have removed contradictory comments to this goal.*

Reviewer #1

The review of vulnerability indicators in this paper is competent. The novelty of the contribution lies in the attempt to compare approaches for earthquakes and floods, and to see what lessons can be transferred from one to the other. This is quite valuable and moderately innovative, and the paper is generally well written, with a few minor lapses.

- *We thank the reviewer for the positive feedback and thorough comments, and are pleased that they value the scientific relevance of our research. The reviewer provides several very useful comments/suggestions for revisions and we have addressed these in the revised manuscript, as per our responses to each comment below.*

I tend to disagree with the fundamental basis of the approach adopted in this paper, in which vulnerability is broken down into sectors - physical, social, psychological, environmental, technical, environmental, etc. - and then recombined. I believe this is inefficient and it glosses over processes that involve several of the sectors at once. A better way to classify vulnerability is based on process (Alexander 1997, p. 292). For example, vulnerability can be seen in relation to the approach taken to manage it, or in relation to factors that enhance it such as corruption, organised crime and technofixes.

- *We acknowledge the strong interactions that exist between the different components of vulnerability, however in comparing different vulnerability assessments, we believe singling out the separate components of vulnerability and its indicators is merely done to simplify the ability to compare the different indicators rather than to disregard the existing interactions. Based on the review comment, we have added the following text (including line number for reference):*

  [130] Several studies have discussed the approach to, and potential pitfalls in, defining different indicator categories (e.g. Davidsson and Shah, 1997; Bruneau et al., 2003; Birkmann, 2007). Bruneau et al. (2003) suggest a framework for the quantitative assessment of seismic resilience consisting of the following four interrelated dimensions of community resilience for which there exists no single measure (note: their definition of resilience overlaps in part with the definition of vulnerability used in this paper): technical, organization, social, and economic. Davidsson and Shah (1997) acknowledge the necessity of the development of "an index of vulnerability". Their Earthquake Disaster Risk Index (EDRI), a composite index, allows for the inclusion of different factors of vulnerability (i.e. physical infrastructure, population, economy and social-political system) (Davidsson and Shah, 1997). Davidsson and Shah (1997) too, acknowledge that factors (or classes) of vulnerability are not distinct entities and that there are many interactions, overlaps and contradictions between indicators from the different classes. While acknowledging the difficulties in categorizing vulnerability, using categories as used in many flood and earthquake vulnerability assessments, we classify vulnerability indicators in two main classes: (a) physical indicators that pertain directly to characteristics of the exposed assets, namely infrastructure and lifelines (including transportation infrastructure, utility lifelines, and essential lifelines) and buildings (including structural elements, occupancy, and environment related factors); and (b) social indicators, which include here: demographics, awareness, socio-economics, and institutional factors (e.g. Mileti, 1999; Cutter et al., 2003; Adger, 2006; Messner and Meyer, 2006; Roberts et al., 2009; Balica et al., 2012).

- *We thank the reviewer for bringing these relevant papers to our attention. We have added a sentence acknowledging that the processes involved in measuring quantitative vulnerability has its shortcomings and is much more complex than assumed in this paper as this is outside the scope of our study. We therefore added the following:*

  [81] Most of the risk models, however, make simple assumptions on quantifying vulnerability, and have largely refrained from considering (changing) vulnerability as a potential cause of the growing impacts of floods (Koks et al., 2015b; Mechler and Bouwer, 2014). Several key challenges with the quantification of vulnerability to flooding include: (1) difficulties in developing meaningful and quantifiable indicators of vulnerability; (2) a lack of available and accurate data to measure those indicators, and the fact that the required data are often only available at highly aggregated levels; and (3) a lack of empirical data on flood losses to relate losses (damage) to vulnerability (Birkmann 2006; Thieken et al., 2008; Notaro et al., 2014).

- *We included the following references:*
  - Alexander, D. (1997). The study of natural disasters, 1977–97: Some reflections on a changing field of knowledge. Disasters, 21(4), 284-304.
  - Pescaroli, G., & Alexander, D. (2016). Critical infrastructure, panarchies and the vulnerability paths of cascading disasters. Natural Hazards, 82(1), 175-192.

Another factor that is increasingly important is the cascading disaster. The principal vulnerability may lie at the escalation point, not in relation to the triggering event (Pescaroli and Alexander, 2016). With the increasing complexity and interconnectedness of society, cascading disasters are going to become very important indeed.

- *We acknowledge the emergence of the scientific field studying cascading disasters (Pescaroli and Alexander, 2016) and agree there is a strong relationship between vulnerability and the propagation of cascading disasters (Pescaroli and Alexander, 2015). However, due to the complex nature of addressing cascading disasters, our study focuses on assessing and comparing separate single-hazard assessments rather than cascading ones. To that extent, we have added a sentence narrowing our scope to exclude cascading disasters and we better explained that the research focuses on single events, while acknowledging the importance of increasing the understanding of cascading events. We added the following sentences:*

  [107] We recognize that the study of cascading events is an important, emerging field as discussed extensively in Pescaroli and Alexander (2016), however our focus is on single events only.

  [822] More studies are looking into cascading events. We recognize this as an emerging field, and believe this field will benefit from further comparative research, involving more models and methods.

As this is a review paper, the authors might consider examining a few references that have been left out (Cardona and Carreño 2011, Holand 2015, Papathoma 2011).

- *We thank the reviewer for these recommendations and we have included the following references:*
  - Cardona, O. D., & Carreño, M. L. (2011). Updating the indicators of disaster risk and risk management for the Americas. IDRiM Journal, 1(1), 27-47.

- Holand, I. S. (2014). Lifeline issue in social vulnerability indexing: A review of indicators and discussion of indicator application. Natural Hazards Review, 16(3), 04014026.
- Papathoma-Köhle, M., Kappes, M., Keiler, M., & Glade, T. (2011). Physical vulnerability assessment for alpine hazards: state of the art and future needs. Natural Hazards, 58(2), 645-680.

Without wishing to suggest huge extensions, I feel uneasy about the lack of reference to the parallel development of resilience indicators. This is now a favourite topic of authors in the DRR field and, of course, it reflects the 'other side of the coin' with respect to vulnerability indicators.

- *We agree that this is very important, and have therefore added the sections outlined below. However, we are cautious to open up a discussion regarding the differences between resilience, and susceptibility and how they relate to vulnerability. We now carefully explain our focus on susceptibility in the introduction and method sections, and we now clearly state which work with the definitions of vulnerability and susceptibility as defined by UNISDR as shown by adding the following paragraphs:*

  [67] While acknowledging the studies that further subdivide vulnerability into resilience and susceptibility, or that consider resilience to be vulnerability's counterpart (e.g. Fuchs 2009), we will only assess vulnerability as it is defined by UNISDR (2009).

  [213] The definition of social vulnerability is much debated (Birkmann 2007). Hinkel (2011) states that although the debate around the conceptualization of social vulnerability continues to exist, agreement seems to have been reached on social vulnerability being context-specific and place-based as defined by Cutter et al. (2003). In this paper, we therefore use the definition of social vulnerability as provided by Cutter et al. (2003) where social vulnerability consists of social inequalities (i.e. social factors that influence peoples' susceptibility) and place inequality (i.e. factors such as urbanization and economic vitality that impact the social vulnerability of a place).

  [225] Two research communities have assessed social vulnerability quite extensively: the climate change adaptation (CCA) community and the disaster risk reduction (DRR) research community (Turner et al., 2003; Thomalla et al., 2006; Mercer, 2010; Dewan, 2013). Concepts from both communities have become increasingly intertwined, integrating concepts of resilience and adaptive- or coping-capacity (e.g. Turner et al., 2003; Deressa, Hassan and Ringler, 2008; Kienberger et al., 2009; Merz et al., 2010; Scheuer et al., 2011; Brink and Davidson, 2015). Birkmann et al., (2013) provide an extensive overview of vulnerability perspectives and discuss the framing of vulnerability by both communities the DRR and CCA communities. Since many risk assessment models use the concept of susceptibility in assessing vulnerability (Birkmann et al., 2013) and since this is in line with the UNISDR (2009) definition of vulnerability, we will exclude resilience as a separate concept.

Lines 13-14: "Next, a selection of index- and curve based vulnerability models that use these indicators have been described" - has been described

- *We thank the reviewer for pointing this out and have adjusted the sentence accordingly.*

Lines 29-47: There is confusion between hazard and vulnerability here. The wording needs to be sorted out. The authors should refer here to some of the work of Roger Pielke Jr on assessing trends in hazard and vulnerability.

- *We thank the reviewer for their suggestions and acknowledge that our wording was not phrased carefully enough. We have adjusted the mentioned section and added the suggested citation.*

  [43] In this paper, we use the widely-applied definition of vulnerability as provided by UNISDR (2009). The paper specifically does not aim to produce another definition of vulnerability and we gratefully acknowledge the broad literature on vulnerability and previous discussions of definitions and conceptualizations of vulnerability (e.g. Alexander 1997; Cardona 2004; Cutter et al., 2003; Adger, 2006; Barroca et al., 2006; Birkmann et al., 2007; Hinkel, 2011).

  [50] Many studies have suggested that the observed increase in risk in recent decades is mainly due to the increase in exposure of assets and people in hazard prone areas, and an increase in wealth (Pielke Jr and Downton, 2000; Kron, 2005; UNISDR, 2011; IPCC, 2012; Doocy et al., 2013b; Blaikie et al., 2014; MunichRe, 2014; Visser et al., 2014; GFDRR, 2016). To date, most studies on flood risk have found little signal for increasing hazard in the last decades (e.g. Kundzewicz et al., 2014; Jongman et al., 2015). However, recent research suggests that this could be due to the fact these studies have not accounted for changes in vulnerability over time (e.g. Mechler and Bouwer, 2014; Jongman et al., 2015) and the impact of risk reduction policies on flood damage and societal flood vulnerability is not well understood (Pielke Jr and Downton, 2000). Indeed, the quantification of vulnerability in risk assessments is known to be extremely difficult, which is why most studies assume constant vulnerability over time.

Line 50: vulnerability curves, conceptualised in engineering as fragility curves

- *We acknowledge that we did not carefully explain the difference between vulnerability curves and fragility curves, nor how we have included them in our study. Therefore, we have adjusted the following two paragraphs.*

  [90] The quantification of vulnerability is most advanced for earthquake risk assessment models although challenges remain (Douglas 2007; Roberts et al., 2009). Historically, the assessment of physical vulnerability (often referred to as 'fragility') is well-developed and recently it has been attempted to improve the quantification of social vulnerability as well (Sauter and Shah, 1987; Tiedemann, 1991; Yücemen et al., 2004; Carreño et al., 2005; Douglas, 2007; Roberts et al., 2009).

  [322] Unlike most other hazard type risk assessments, earthquake risk assessments traditionally use fragility curves as a vulnerability, or expected damage, measure, in which probabilistic damage to, for example, buildings is related to a hazard parameter such as ground shaking intensity (Douglas, 2007). In this study, we grouped fragility curve based models with other curve based models.

Lines 115-120: Indicators for cascading disasters and their escalation points are needed.

- *Please see our earlier comments regarding cascading events.*

Line 131: "The vulnerability of both infrastructure and buildings are influenced" - is influenced.

- *We thank the reviewer for pointing this out and have adjusted the sentence accordingly.*