Integrated Tsunami Vulnerability and Risk Assessment: application to the coastal area of El Salvador

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Author's response to Anonymous Referee #1

First of all we would like to thank this Referee for accepting to review this paper and for the constructive comments provided.

According to the suggestions made by the Referee, we have carried out an extensive revision of the paper and we proceed in this document to answer all the comments. As many of them required extensive, explanatory and detailed answers, the referee comments are presented in black bold font followed by the authors' answers in blue font.

The paper is very relevant to NHESS and presents new data from a case study area in El Salvador. Conceptually, although the authors note that an improved framework is presented, the advances are modest (see further comments below).

The authors have gone at length at looking into the vulnerability and risk literature, but have omitted the concept of coupled social-ecological systems in their analysis, thus not accounting for important feedback loops that operate between subsystems and process at various scales, which is a limitation of the classical approach that they used. It would be important to justify this in the text as social-ecological systems (as coupled systems) are central to most contemporary risk and vulnerability assessments (you also talk of systems in page 2885).

The authors acknowledge the relevance of the concepts of coupled social-ecological systems and related feedback loops suggested by the Reviewer. These concepts have been explicitly included in the revised paper. The authors would like to mention that the integrated approach and the understanding of the interrelationships that control the behavior of the system mentioned in the paper by the authors aimed to deal with this complexity of coupled social-ecological systems.

The approach used is classical and I am not certain that it is an advance per se from existing frameworks. The framework in Figure 1 is, from my perspective, rather simple, e.g. when comparing it to the Turner et al framework reviewed in this manuscript or the MOVE framework described by Birkmann et al (2013, in Natural Hazards). Feedback loops are not considered as well as e.g. policies enacted outside the place of vulnerability. In this sense the work is close to that of e.g. the World Risk Report or that of Damm (2010 - http://www.ehs.unu.edu/file/get/8056). This is not strictly problematic but my suggestion is that the review sections (1 & 2) and the more general methodological considerations (e.g. section 3.2.1 and 3.2.2) could be condensed in order to provide more space for the justification of indicators and other aspects I discuss below.

Following the referee suggestion, the review and methodological sections have been greatly condensed in order to provide more space for the justification of the indicators and other aspects. As mentioned in the previous paragraph, feedback loops have been highlighted in the analysis.

The wording of the paper has been revised to better express the purpose of the work, as the main expected contribution is to provide a straightforward method to facilitate the implementation of concepts provided by existing theoretical frameworks and approaches such as the MOVE framework (Birkmann et al., 2013), Turner et al. (2003) or the BBC conceptual framework (Bogardi and Birkmann, 2004; Cardona, 1999, 2001). The implementation of these theoretical concepts to case studies is sometimes complex due to site-specific problems, lack of data or the lack of information about particular methodological aspects.

What is missing in the paper is a justification for the various components of the model. For example, why use resilience under vulnerability as, as is discussed in the paper, some see resilience as the flip side of vulnerability while others consider these as two different concepts? This is a particular interesting discussion point because when you derive indicators (Table 2), these are capacity indicators (coping, recovering). So why use "resilience" terminology and not simply stick to "capacities" which is also used in other frameworks? I appreciate that resilience is a trendy word/concept, but in this case, I do not think you are really talking about resilience (in the sense of e.g. the resilience alliance or even of the UNISDR definition you quote on page 2890).

A justification for the components of the model is provided in the revised paper (Section 2), paying special attention to those that are slightly different to the ones suggested by official definitions, i.e. risk, vulnerability and resilience, the revised paper being consistent with these definitions. More precisely:

(i) Risk & uncertainties: the fact of using a deterministic analysis does not allow providing the risk results in terms of a probability of negative consequences; instead it permits the identification, location and quantification of the expected negative consequences or impacts for the worst possible credible scenario (as carried out by Jelínek et al., 2009, within the TRANSFER Project). These results allow the authorities of the country organizing and managing the risk according to the most protective situation.

(ii) Vulnerability vs. resilience: the vulnerability conditions are here understood to be of two types, internal (unchangeable individual conditions, such as the age of the population) and external (changeable community conditions, improvable through learning and experience, such as the risk preparedness within the communities), the improvement of the latter being a possible countermeasure to reduce the vulnerability of highly sensitive areas. Accordingly, *sensitivity* refers to the intrinsic characteristics of the exposed elements that make them potentially affected; while *resilience* is the ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner.

(iii) Resilience vs. capacities: the resilience of a community with respect to potential hazard events is determined here by the degree to which the community has the necessary resources and is capable of absorbing disturbance and re-organizing into a fully functioning system (Cutter et al. 2006). We understand this idea as the capacity of a community to organize itself before, during and after the event in order to minimize the impacts. And this capacity at various moments of the event is translated into coping and recovery capacities, providing several variables to assess their level and consequently their progress when

measures to enhance the resilience are implemented. The approach applied is consistent, in our opinion, with the resilience definitions provided by widely-known institutions and authors (UN/ISDR, 2009; Cutter et al., 2006, US IOTWS 2007).

As indicated above, regarding the spatial dimension, what is missing in my opinion is the consideration of factors shaping risk at various scales, e.g. policies at the international or national level increasing (or reducing) the vulnerability of communities at the local level (cf. the Turner model, for example).

The inclusion of this type of factors was slightly considered in the previous version of the paper through the variable "Number of persons exposed temporarily (holidays)" within the Human exposure indicator, that permits the comparison of specific areas at different times of the year (spatio-temporal variability), perceiving higher exposure and vulnerability values in holiday periods. This effect in specific hotspots is explained by holiday movements of foreigners to very specific sites and associated for example with surf promotion campaigns developed at the national level. These overcrowded places are likely to be higher risk areas in holiday periods. Other factors could be the planned coastal development for the coming years in exposed areas, or national initiatives (like the one resulting in this paper) which are aimed at reducing the vulnerability of communities at the local level. Following the suggestion of the reviewer these factors are mentioned in the revised paper.

With respect to environmental sensitivity, I am not sure I understood the argumentation completely. In table 5, you address losses of protected ecosystems, etc. Looking at impact variables in a vulnerability assessment is problematic – indeed from Table 5 and from your discussion on this specific section (you mention damages to mangroves, to specific species), one could infer that a simple policy measure to reduce the sensitivity in the environmental sphere would be to cut all mangroves and eliminate the various endangered species. I am of course here being provocative, but an area with cemented beach front would turn out as less vulnerable (after aggregation) than one with mangroves, if I followed your assessment correctly. However, I might have missed something important in your argumentation and misunderstood your analysis. When considering the environmental sphere, I would infer on the contrary, that an area with mangroves might reduce the overall social-ecological system vulnerability (I admit this is debated scientifically) even if the mangrove itself is destroyed in the process, which bring me back to the lack of "systems thinking" for the proposed framework. In the end we do not know who's or the vulnerability of what you are measuring.

The definition and explanation of the vulnerability has been clarified in the revised paper in order to avoid the suggested misunderstanding.

The sensitivity assessment focuses on the **expected impacts by municipality on the different dimensions and their potential worsening implications for the populations due to existing feedback loops** (for example, the loss of household income due to loss of livelihood-related natural resources, the loss of recovery capacity of the country due to the loss of area of specific socioeconomic activities, or the lack of long-term water resources due to the affection of coastal wells, among others). What we are measuring at the national level is the vulnerability of each municipality regarding the different dimensions to understand the expected human, environmental, socioeconomic and infrastructural impacts.

Accordingly, the Environmental Sensitivity indicators (S7-S10) aim to assess the potential **environmental impacts** by municipality in terms of loss of ecosystems and the subsequent loss of livelihoods-related

ecosystem services. Thus, the loss of relevant ecosystems (S7, S8, S9), the potential permanent destruction of ecosystems (S10), and the loss of livelihood-related ecosystem services such as coral reefs and mangroves (S8) is assessed. The potential capacity of mangroves to mitigate the hazard is included in this work through the hazard assessment as a higher roughness coefficient was assigned to mangrove areas.

As the aim is to identify and locate the expected impacts on the various dimensions, the sensitivity indicators are always related to the potential loss of valuable exposed elements. Cutting the mangroves and eliminating species would mean that the environmental exposure is null and consequently the environmental sensitivity too. Continuing with the example proposed, an area with cemented beach is definitely less vulnerable in terms of expected environmental impacts. When mentioned in the paper that *risk management requires an integrated and holistic understanding of the coupled human-environmental system dealt with; otherwise management options can produce unexpected and sometimes undesired results*, we mean these kind of individual policy measures suggested as an example by the reviewer to reduce the sensitivity in the environmental sphere by cutting all mangroves and eliminating the various endangered species. Cutting the mangroves would reduce the **environmental value** of the study area instead of the **environmental sensitivity**. The importance of the integrated approach is exactly this, understanding the global system to reduce the vulnerability in a sound way without harming the (human, natural, socioeconomic) resources and community development capacities.

Regarding the lack of systems thinking, the authors are aware of the importance of understanding the feedback loops existing in coupled social-ecological systems and, in that regard, perceive two different and complementary aspects for this concept depending on the reference to specific static assessments or to holistic and time evolving management. The sensitivity assessment is carried out in this work for a specific moment, it can be seen as a snapshot in time or a statistic state (as described by Cutter et al., 2008, for the antecedent conditions of resilience), the result being a precise value for each partial sensitivity (human, environmental, etc.) independently of the existing feedback loops within the system. Feedback loops are essential, in our opinion, and are considered in this work as the only way to understand the behavior of the system and to correctly manage it in terms of risk reduction, this being the reason for designing the set of indicators through the integrated approach.

Another aspect that should be discussed in the paper is that of uncertainty and critical assessment of the approach. These indicator based approaches are very useful, but have also some shortcomings which need to be discussed. An example is the need to quantify everything – this is particularly evident when you compute resilience (Table 6) and provide a resilience index on what is basically qualitative information.

Following the suggestion of the reviewer, the aspects of uncertainty and a critical assessment of the approach have been included in the revised paper.

Regarding the modeling of uncertainties and as mentioned before, the deterministic analysis applied permits the identification, location and quantification of the expected damages, negative consequences or impacts for the worst possible credible scenario, which is essential information to foster the community preparedness according to the most protective situation.

The justification and critical assessments regarding the mixed indicator approach have been included in the revised manuscript. More precisely, the main justification relies on the understanding of all the potential implications of a tsunami event in a specific area (expected impacts by municipality on the different

dimensions and their potential worsening implications for the populations due to existing feedback loops) which will help in promoting awareness and preparedness for example. On the other side, this global understanding of the system has the disadvantage of sometimes resulting into a shallow analysis on some of the impacts analyzed.

The authors agree that the resilience assessment is based on subjective qualitative information as it is based on questionnaires. However, we believe that qualitative information can also be used for vulnerability indicators when no quantitative data exist. An analysis of a single municipality may not require a resilience index (i.e. numerical); however, when a comparison between municipalities is required (which is the aim of the national assessment) the resilience index seems to be a possible approach to have a general idea of the state of each municipality in terms of their preparedness and emergency management. The results of the resilience index at the national level allow understanding in a general and preliminary way the main weaknesses in emergency management, in order to design further detailed analyses to propose weakness-oriented site-specific corrective measures. Besides, in case of contradictory answers, the incoherence between authorities' and society's perception about the preparedness of the municipality is automatically identified as a critical issue for resilience enhancement measures.

The approach also assumes that we are considering some sort of continuous domain whereas I would argue that risk assessment might actually consist of discontinuous functions. Taking resilience as an example, you might have a situation where municipalities would say they have everything you propose in Table 6 underway, except e.g. early warning systems and evacuation routes. Yet, the municipality would end up with a "good" resilience score, whereas it is clear that lack of tsunami early warning and evacuation routes put communities at extreme risk with respect to this hazard, regardless o anything else being done positively in other domains. These limitations should, in my mind, be critically assessed in your paper.

Following this suggestion the limitations of the approach have been analyzed, included and discussed in the revised paper.

Answering to the comment, the importance of each indicator or variable and the critical role of some of them within the assessment have been considered through the weighted aggregation. Weights have been assigned through the opinions of different experts, in order to reflect political and social priorities, technical factors related to the tsunami hazard and the reliability of the data used. Accordingly, in the case of resilience, coping capacity is weighted more than the recovery capacity due to the prioritization of saving lives, and resilience is weighted less than sensitivity due to the use of more subjective information. The workshop made evident the difficulties in weighting the different resilience variables: the first impulse for almost everyone was to give higher weights to the suggested topics (early warning system and evacuation routes), however a lack of social awareness regarding evacuation (question 1) or a communication and coordination malfunction between the different warning responsible levels (questions 7, 9, 10) could turn a tsunami warning ineffective. Another example regarding social awareness in the case of a local tsunami, a community informed and trained about the tsunami hazard would start evacuating just after feeling the earthquake, which could save valuable time before the warning is issued and hopefully lives.

In addition, the aggregated result (sensitivity or resilience) per se is not the final aim of the work, but the generation of information for the formulation of risk reduction measures; i.e. what we get from the resilience assessment is the identification of site-specific topics that should be managed before a tsunami event happens. Besides, the advantage of the approach is the availability at every moment of each partial result, which avoids losing information when aggregating results. In other words and as an example, we

know in which municipalities we should work on designing evacuation routes, and in which ones we must focus on social awareness or early warning system, which is the aim of the assessment. With the sensitivity results happens the same, we know in which municipalities a specific attention must be paid regarding the evacuation of critical buildings such as schools, hospitals, geriatrics etc., or where we should plan an alternative water supply for coastal communities with potential polluted wells, or where specific information and training campaigns must be designed for isolated areas or municipalities with a large amount of people with difficulties to understand a warning message.

Specific comments:

P2884: the sentence "but they nonetheless represent a greater threat than earthquakes, hurricanes and tornadoes" needs to be justified. I do not necessarily agree with "greater", in particular when considering earthquakes. Furthermore, tsunamis are often triggered by earthquakes, as you note in the paper.

This sentence has been removed as both reviewers didn´t agree with it.

P2887: I suggest you abstain for naming all the frameworks, particularly since these are extracted from Birkmann (2006). A reference to this review paper would be sufficient, in my opinion.

The frameworks names have been removed, just referencing to Birkmann's paper.

P2887: you mention that several gaps in science have been identified. Please indicate by who (reference).

These gaps were identified by the authors when trying to find a straightforward methodology to implement a risk assessment in an integrated way. However, the revised paper does not include this paragraph.

P2888: I would replace "bewildering" by "large".

The word "bewildering" has been replaced

P2893 L15: what do you mean by "climate change hazard"?

Climate change-related flooding. This change has been included in the revised paper.

P2893 section 3.1: do you consider modeling uncertainties and if so how? Also, I suggest you avoid using "shall".

Modeling uncertainties is not considered in this work as the hazard assessment is based on a deterministic analysis. The expected negative consequences or impacts for the worst possible credible scenario are identified, located and quantified.

The word "shall" has been removed.

P2896 L3: I do not think that you mean that your indicators were selected based on the general OECD guidelines step by step procedures. This raises the question as to how you decided on the proposed set of indicators presented in Table 2 – this is not discussed at all in the paper. Did you consider indicator cross-correlation? It seems to be the case, but there is no evidence for this in your paper.

OECD steps have been considered for the design of the composite indicator system; however the information about index creation has been greatly condensed. Information about the generation of the set of indicators has been included in the revised paper, justifying the aim of each indicator, data sources and

classification method. The definition of variables has been a trade-off between the desired assessment and the available information. Advantages and disadvantages of the mixed indicator approach have been identified.

The Pearson correlation coefficient was calculated to select the indicators. The revised paper includes this explanation. Most of the indicators were low correlated except *Extreme poverty* & *Illiteracy* (r=0.92), *Environmental threat* & *Protection* (r=0.68), and *GDP contribution* & *Job generation* (r=0.90). These relationships between variables were carefully evaluated to consider the removal of some of them; however, their analytical relevance and differentiation prevailed to the correlation result, as agreed by the assistants to the participatory workshop and for the sake of better refined risk reduction measures. In this sense, (i) Poverty gives information about areas which will struggle more after the event due to the lack of financial resources to recover, while Illiteracy provides information about the ability to understand a warning message during the event; (ii) maintaining both Threat and Protection indicators permitted to identify areas where not-protected endangered species were located and formulate specific measures for these areas; (iii) maintaining both GDP contribution and Job generation permitted to clearly differentiate between social and economic impacts of the event to understand the medium-long-term effects of the tsunami. Weights have been carefully assigned to these indicators to correct the doubling effects when aggregating.

P2896 L24: who was questioned through the questionnaire?

The resilience questionnaires have been filled in by the person in charge of the Municipal Civil Protection Committees of all the municipalities under study, some non-governmental organizations, companies and business associations, and community leaders. In total 34 persons were interviewed.

P2897 section 3.2.2: this section is too detailed and reports already exist for these step descriptions. I suggest you reduce the length of the explanations by simply providing the adequate references.

Following this suggestion, Section 3.2.2. has been condensed and references have been included.

P2900: you could mention explicitly ecosystem-based measures within you nonstructural measures (you have them in Table 4). These are critical in coastal settings, and brings me back to the issues related to environmental sensitivity discussed above.

Table 4 has been removed from the paper according to Reviewer 2 suggestion

P2902 L16: replace "affection" by "impacts"

The word "affection" has been replaced

P2904: I would suggest your replace "are highlighted" with relevant sensitivity qualifiers.

According to Reviewer #2, the analysis of results has been reoriented to identify practical lessons learnt from the work that can be useful for international readers (i.e. not familiar with El Salvador). Thus, the paragraph related to this comment has been removed.

L23 you mean "human sensitivity graph" or "social dimension graph"? Same comment for "environment".

We meant human dimension graph, environmental dimension graph, etc. Nonetheless, according to Reviewer #2, the analysis of results has been reoriented to identify practical lessons learnt from the work

that can be useful for international readers. Thus, the paragraph related to this comment has been removed.

P2907 and Figure 15: you provide here quite exact figures on economic losses and it is not clear from your paper how you achieved this.

These figures are obtained through the indicators shown in Table 2 (E3, S11, S12 and S13): exposed area of every specific socioeconomic activity, and related contribution to job generation (number of workers), GDP and foreign trade (millions of USD).

Figure 2: I would suggest you explain all the symbols in the caption).

Figure 2 has been modified, and the symbols have been replaced with the words they represent.