

## ***Interactive comment on* “From Tsunami Risk Assessment to Disaster Risk Reduction. The case of Oman” by Ignacio Aguirre Ayerbe et al.**

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RESPONSES TO REFEREE #1

Dear reviewer,

First, we really appreciate Referee’s #1 valuable comments and suggestions, which offer us an opportunity to improve the paper. We found all comments and additional references provided very interesting and believe that consequent changes in the paper represent an improvement over the initial submission. Below you will find your comments followed by our response. We have also attached a new version of the manuscript (Aguirre-Ayerbe\_From TRA to DRR\_Discussion\_Manuscript\_v2) with the

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changes proposed after your suggestions, marked in green. In addition, you will also find the changes anticipated following the suggestions of a second reviewer, which are highlighted in blue. Lines referred in this author's response are the lines numbered in the version 2 of the manuscript, which is attached to this response.

General comments **GENERAL COMMENTS:** How can you evaluate that your goal was succeed for tsunami DRR even if there is no actual tsunami event to test? Of course, I agreed if your goal is to develop some tools or frameworks for DRR and to say that the country will be more prepared. Otherwise, please give some examples (may be in other countries?) to support that in what way, what you have achieved in this project can reduce tsunami risk in the future. Risk communication is also very important. Good quality of DRR countermeasures will be meaningless if they were failed in transferring to people at risk. Also, I could see that you mentioned about education, but I think it should be explained more on how the people at risk will be properly/correctly educated and have high capacity enough to receive risk information from the government, etc.

**GENERAL RESPONSE:** We agree with your general comment, the goal of this study is to develop and provide a framework and some tools to improve the preparedness of the country to a tsunami event. The tsunami risk assessment performed, together with the risk reduction measures identified are essential for the risk-management preparedness strategy. Thus, improving preparedness will rise the capacity of the country in facing a tsunami event.

We also agree with your comment regarding risk communication and education. Risk communication and education helps to raise awareness and consequently improve effectiveness of certain measures. Performing a tsunami hazard, vulnerability and risk atlas as well as risk reduction measures handbook is a pillar for communication processes. Risk assessment and mapping is indeed the first step in the risk management process. Without these tools is not possible to have proper knowledge of the potential problem. These tools were developed to be included in the tsunami risk management

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process, but actual implementation into government policies and institutional communication strategy or educational official curricula goes beyond the scope of this work. It is precisely the next step from this study. This idea has been included in current lines 427-428. Specific comments 1. REVIEWER COMMENT: Title: I feel that the title is rather general and should be modified to be more attractive. RESPONSE: We agree with the reviewer in the idea that the title is rather general. However, the objective that led us to define this title was an attempt to synthesize what is presented as much as possible through the main keywords, i.e. tsunami/risk assessment/disaster risk reduction/in Oman, so that anyone interested in the topic and in the topic in Oman will easily find this article. We prefer and suggest keeping the current title.

2. REVIEWER COMMENT: Abstract: I feel that the main results of your study did not appear in the abstract. I would also write about the recommended countermeasures, recommendation for DRR in Oman here. RESPONSE: We totally agree. Following this recommendation, a paragraph has been included highlighting main results (please, see current lines 19-22).

3. REVIEWER COMMENT: Introduction: You may split this part into three sections: 1) tsunami hazards in Oman, 2) risk assessment method and 3) your study objectives. RESPONSE: We agree with the structure proposed by the reviewer, which is indeed the structure followed. We have tried to divide in the proposed sections but they fragment too much the introduction, which is not so long (just one side) to integrate subdivisions, so we decided to redo and suggest the initial proposal.

4. REVIEWER COMMENT: Introduction: These are other studies on tsunamis in MSZ and should be properly credited. I remember that one of them also use high resolution of bathymetry in Oman. Heidarzadeh M, Kijko A (2011) A probabilistic tsunami hazard assessment for the Makran subduction zone at the northwestern Indian Ocean. Nat Hazards 56:577–593. Heidarzadeh M, Satake K (2014a) New insights into the source of the Makran tsunami of 27 November 1945 from tsunami waveforms and coastal deformation data. Pure Appl Geophys 172(3):621–640 Heidarzadeh M, Sa-

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take K (2014b) Possible sources of the tsunami observed in the northwestern Indian Ocean following the 2013 September 24 Mw 7.7 Pakistan inland earthquake. *Geophys J Int* 199(2):752–766

Heidarzadeh M, Pirooz MD, Zaker NH, Synolakis CE (2008a) Evaluating tsunami hazard in the Northwestern Indian Ocean. *Pure appl Geophys* 165:2045–2058

Heidarzadeh M, Pirooz MD, Zaker NH, Yalciner AC, Mokhtari M, Esmaeily A (2008b) Historical tsunami in the Makran Subduction Zone off the southern coasts of Iran and Pakistan and results of numerical modeling. *Ocean Eng* 165:2045–2058

Heidarzadeh M, Pirooz MD, Zaker NH (2009) Modeling the near-field effects of the worst-case tsunami in the Makran subduction zone. *Ocean Eng* 36(5):368–376

Latcharote, P., Al-Salem, K., Suppasri, A., Pokavanich, T., Toda, S., Jayaramu, Y., Al-Enezi, A., Al-Ragumand, A. and Imamura, F. (2017) Tsunami hazard evaluation for Kuwait and Arabian Gulf due to Makran Subduction Zone and Subaerial landslides, *Natural Hazards. RESPONSE: We appreciate the reviewer information regarding additional references. One of them was already cited. The rest of them have been included (please, see green coloured highlights in section 1 Introduction).*

5. REVIEWER COMMENT Page 2 lines 40-43: This way of citing is not so good. Because you are mentioning three different risk targets (building, infrastructure and human), readers will not know that which reference did what. - There are recent studies on the vulnerability of the mentioned risk targets (in addition to building). Suppasri, A., Fukui, K., Yamashita, K., Leelawat, N., Ohira, H., and Imamura, F.: Developing fragility functions for aquaculture rafts and eelgrass in the case of the 2011 Great East Japan tsunami, *Nat. Hazards Earth Syst. Sci.*, 18, 145-155. Shoji, G. and Nakamura, T.: Damage assessment of road bridges subjected to the 2011 Tohoku Pacific earthquake tsunami, *Journal of Disaster Research*, 12, 79–89, 2017. Suppasri, A., Latcharote, P., Bricker, J. D., Leelawat, N., Hayashi, A., Yamashita, K., Makinoshima, F., Roeber, V. and Imamura, F. (2016) Improvement of tsunami countermeasures based on lessons from the 2011 great east japan earthquake and tsunami -Situation after five years-, *Coastal Engineering Journal*, 58 (4), 1640011. Suppasri, A., Muhari, A., Futami, T., Imamura, F. and Shuto, N. (2014) Loss functions of small marine vessels based on

surveyed data and numerical simulation of the 2011 Great East Japan tsunami, *Journal of Waterway, Port, Coastal and Ocean Engineering-ASCE*, 140 (5), 04014018. RESPONSE: We agree with this reviewer's comment. The initial idea was simply to highlight the difference between different approaches from a wider point of view, but we think the reviewer comment is appropriate and have made changes following this suggestion. We have also included two of the references suggested in this comment (Suppasri et al., 2018 and Shoji and Nakamura 2017). Please see all proposed changes along the current lines 45 to 50.

6. REVIEWER COMMENT: Methodology: You may write section name 2.1, 2.2., 2.3. . . in Fig. 1. RESPONSE: Numbers in figure 1 represent the different orderly steps in which the disaster risk reduction is carried out in this study. However, sections of the document do not follow exactly the same numbering (for example, exposure and vulnerability are treated and explained together). Therefore, we believe that writing section numbers in the figure would be confusing since they would be different from the current ordinal numbers (1 to 6). As the reviewer can verify, explanation of the figure including the corresponding sections is already included in current lines 78-95.

7. REVIEWER COMMENT: 2.1: Please give a reference that other source of tsunamis such as landslide or volcanic eruption can be neglected. RESPONSE: In this study, we have just considered potential earthquake sources for the tsunami risk assessment. We cannot neglect other source for tsunami generation in the area. We have slightly modify the sentence in current line 127 to make it clearer that in this study we have considered only earthquake sources.

8. REVIEWER COMMENT: Page 5 line 129: "Okada model" should be properly cited giving the year and put in the reference - Please also tell readers about your computational grid size. Although the simulation was done by your previous study but the grid size is important to understand the resolution of your study. - Please give some comments if the tsunami sources in your study the same or different to other previous studies. RESPONSE: We thank the reviewer for this comment. We forgot to include

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Okada reference. This has been now included in current line 135 and 593. Regarding resolution, it is included in current line 137.

Tsunami sources are original from our study. Just one is based on previous studies (Heidarzadeh et al., 2008) and included in the manuscript in the current line 148. There is another scientific article detailing this process in preparation and will be submitted this month. 9. REVIEWER COMMENT: Page 5 line 145: “drag level” sounds wired to me. I would prefer “drag force” or “hydrodynamic force”. Please check and consider. RESPONSE: According to the reviewer comment, we have made a clarification in current line 152-153, referring to the term also as “depth-velocity product” as it is called in the reference considered (Jonkman 2008), which is a proxy of the drag force to which the reviewer refers to. We have also maintained the concept “drag level” as it is used in previous works, e.g. González-Riancho et al. (2014). Please, see current lines where changes have been made: 152-153 and 212-213.

10. REVIEWER COMMENT: 2.2: I feel that you just mentioned about your risk variables but not on how the hazard and risk will be linked. Few sentences in lines 146-150 is probably rather fit to this section as they explain the linkage between hazard and vulnerability. RESPONSE: After a brief mention in the “methodology” section (current lines 89-93), the main explanation on how hazard and vulnerability are combined may be found in “risk assessment” section (current lines 203-217). We thought it was useful to also include some lines under the “hazard assessment” section, to explain that hazard variables are classified (current lines 154-158). Besides, following the reviewer comment, we have added a clarification (current line 154-155).

11. REVIEWER COMMENT: Table 1: I think age and gender are also important as they are directly related to the evacuation speed. How can you directly applied their proposed vulnerability functions to Oman. For example, building strength in Oman may different to other countries. Did you used different kinds of vulnerability functions for different kinds of buildings/infrastructures? RESPONSE: As information on building materials were not available, we considered as a minimum, based on field observa-

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tions, that buildings included within the infrastructure dimension fit at least with class C1 of Tinti and Valencia references (Brick with reinforced column & masonry filling. One or two storeys), so we used the corresponding damage function.

12. REVIEWER COMMENT: 2.3 Fig. 4:I can see that you used flow depth and drag force as your hazard index. What if both give different results? Low flow depth with high velocity will have high drag force, therefore, you will have lower hazard level when using flow depth but higher hazard level when using drag force. RESPONSE: Yes, that is true. However, the analysis is independent for each dimension. We used drag level (as a proxy of drag force) for the human dimension (based on previous works, among them Jonkman et al., 2008). On the other hand, we used flow depth for the infrastructure dimension (based among others in the work developed by Tinti 2001 and Valencia 2011). Afterwards, we combine each hazard variable level with vulnerability level (for each dimension) to obtain human and infrastructure risk indexes respectively. Both risk indexes can be combined later to obtain an aggregated risk index, thanks to the indicators and indexes system applied. This is explained mainly in lines 212-214.

13. REVIEWER COMMENT: What is the meaning of “assigned score”, how it is assigned and how it was applied to different human and infrastructure index? There should be some explanations about the hazard-vulnerability table, not just only shown in Fig. 4. RESPONSE: “Assigned score” in figure 4 refers to the vulnerability classification, which is mainly described in the “vulnerability assessment” section (current lines 194-197). The classification of the hazard index is described in the “hazard assessment” section (current lines 154-159). Following the reviewer comment and to avoid confusion we have changed Fig.4 to follow exactly the same terminology: instead of “assigned score”, it now says “vulnerability class”.

14. REVIEWER COMMENT:2.4: What is RRM? RESPONSE: RRM is the acronym for “Risk Reduction Measures”. It appears for the first time on page 1 and since then the acronym is used since the term appears 30 times.

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15. REVIEWER COMMENT: Fig. 5: “exposure assessment” have never mentioned before or in any places in your paper but shown in this figure. Please explain in your main text. RESPONSE: Exposure is one of the risk components, as explained in current line 68. It is also stated that exposure is a necessary component (as they are the hazard and vulnerability) for the establishment of risk reduction strategies and measures (current lines 68-70 and 87-93). By exposure assessment, we are referring to the analysis of people, buildings and infrastructures located in a flooded area as described in current lines 88-89 and in the modified ones 181-182. We have also cited, in brackets, the risk components “(hazard, exposure and vulnerability)” (current line 224-225) to improve understanding.

16. REVIEWER COMMENT: In Fig. 2: you show disaster cycle, but you only focused on prevention and preparation in your study. How emergency response and recovery included in your study or will be considered in the future? RESPONSE: Reviewer comment is right. In this study, we have proposed a framework for the whole disaster risk management cycle but focused only on pre-event strategies, prevention and preparedness (please, see current lines 103-105). Post event measures should be considered in the future. Nonetheless, it must be considered that each of the strategies includes several actions that may overlap in time and that may even belong to more than one strategy. In this sense, there are some preparedness measures, which are oriented to the post-event phase of the disaster management, such as contingency planning, stockpiling of equipment and supplies and arrangement for coordination.

17. REVIEWER COMMENT: I can see only section 2.4.1 but no 2.4.2. RESPONSE: Yes. We have included 2.4.1, 2.4.2 and 2.4.3 sections. Please see current lines 269, 285 and 300.

18. REVIEWER COMMENT: Page 10 line 278: How the recommended measures were determined? In what way they were decided that priority to be recommend? Were they determined by hazard reduction performance, economic cost, B/C, impact to environment, etc.? RESPONSE: Risk reduction measures were determined based

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on the technical information described in the RRM-cards (RRM-cards are described in current lines 251 to 257; we have also included a sentence in current lines 290-291 to clarify) and depend on the site-specific conditions that have determined the type hotspot (hotspot determination is explained in current lines 269-284).

19. REVIEWER COMMENT: Results: Fig. 9: How can local people get an access to information like in Fig. 9? RESPONSE: All the information generated in this study have been included in the “Tsunami Hazard, Vulnerability and Risk Atlas” and the “Risk Reduction Measures Handbook”. This information have been transferred to the Government of Oman and it is expected to be used as the main source for policy planning, awareness and education regarding tsunami disaster.

20. REVIEWER COMMENT: 3.3 Page 18 Lines 395-396: How the knowledge can be transferred? Any example? RESPONSE: The knowledge was transferred to government authorities and technicians by means of technical courses on tsunami hazard, tsunami vulnerability and risk, GIS for disaster risk reduction and system procedures and architecture. This capacity building ensure a long-term management of the product developed (as mentioned in current line 410-411). Please, see following links: [http://www.ioc-tsunami.org/index.php?option=com\\_content&view=article&id=269:assessment-of-coastal-hazards-vulnerability-and-risk-for-the-coast-of-oman&catid=20&lang=en&Itemid=68](http://www.ioc-tsunami.org/index.php?option=com_content&view=article&id=269:assessment-of-coastal-hazards-vulnerability-and-risk-for-the-coast-of-oman&catid=20&lang=en&Itemid=68)

[http://www.unesco.org/new/en/member-states/single-view/news/oman\\_launches\\_an\\_early\\_warning\\_system\\_to\\_address\\_](http://www.unesco.org/new/en/member-states/single-view/news/oman_launches_an_early_warning_system_to_address_)

21. REVIEWER COMMENT: Page 18 Line 405: How can you make sure that it will not be just a manual which people will never read? How this manual will be used for various practical actions such as evacuation drills, etc? RESPONSE: This study is the necessary starting point for the reviewer commented actions. Several copies of this manual were delivered to government authorities. Several follow-up meeting were held with different stakeholders to explain the information and discuss the best approaches

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to utilize such information for the planning and implementing policies and strategies. The manual is also expected to be used as the main source for public awareness and educational purposes. The long term follow-up is out of the scope of the work presented.

22. REVIEWER COMMENT: Page 18 Line 411: In what way the warning message can be disseminated to local people or how they can access? RESPONSE: That issue is out of the scope of the presented study. The tsunami early warning system is only accessible for tsunami risk authorities/managers (i.e., DGMET) and they are the responsible to define the emergency protocol.

23. REVIEWER COMMENT: I suggest reorganizing like this 1) the new method used in this study, 2) recommendations to government or local people in Oman and 3) Global applications/limitations of this study. RESPONSE: We thank the reviewer suggestion to reorganize the conclusions section. The structure of this section follows each of the steps (methodology) explained in the paper, in the same order that they are initially presented. Section 3.3 has been maintained under the “results” section since it refers to the outcomes of the study and their usefulness for tsunami risk management in the country. Following reviewer suggestion, we have changed the last paragraph (about stakeholders involvement) leaving the paragraphs about usefulness and overall application of the methodology and brief description of outcomes and their usefulness at the end (please, see current lines 462-469).

24. REVIEWER COMMENT: The Sendai Framework have never appeared in the main text but suddenly mentioned here. If you want to keep this sentence, please also mention in your introduction or methodology on the linkage between your work and the Sendai Framework. RESPONSE: We thank the reviewer’s comment. In fact, this sentence was initially linked to a part of the introduction that was discarded and we forgot to delete it in the conclusions. Sendai framework sentence in the “conclusions” sections has been deleted.

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Please also note the supplement to this comment:

<https://www.nat-hazards-earth-syst-sci-discuss.net/nhess-2017-448/nhess-2017-448-AC1-supplement.pdf>

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