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Interactive comment on "Tsunami evacuation plans for future megathrust earthquakes in Padang, Indonesia considering stochastic earthquake scenarios" *by* Ario Muhammad et al.

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We appreciate Reviewer 1 for his/her positive and constructive comments on the submitted manuscript. The following are our point-by-point responses to the reviewer's comments.

C1 - INTRODUCTION SECTION: In the introduction section, there is a lack of a description of the effects of the 26th December 2004 Indian Ocean Tsunami on the study area. Therefore, I suggest that the authors add a short paragraph in which they are invited to outline the reasons why the study area of Padang, Indonesia, escaped the destructive effects of the 26 December 2004 Indian Ocean tsunami.

Printer-friendly version

Discussion paper

Answer:

The main reason insignificant effects of the 2004 Indian Ocean tsunami in Padang areas is because the source location where the earthquake rupture occurred was far from Padang (i.e. >1,200 km). The 2004 source is centred in the Andaman segment of the Sunda subduction zone which is located in the north-west of Sumatra Islands (Meltzner et al., 2006; Briggs et al., 2006). On the other hand, Padang is located in the centre-west part of Sumatra and therefore, the 2004 tsunami events was not majorly affected this areas.

We added a short paragraph in Introduction describing the effects of the 2004 Indian Ocean tsunami to outline the 2004 Indian Ocean tsunami as follow:

The 2004 Indian Ocean tsunami did not significantly affect this region since the source location of the 2004 event is far i.e. >1,200 km (Natawidjaja et al., 2006; Meltzner et al., 2006; Briggs et al., 2006). However, it is located along the coast of Sumatra Island, directly facing the Mentawai segment of the Sunda subduction zone. Consequently, potential impact of the future tsunami may have significant risk in this area. In addition, with the low-lying plain topographic features in Padang, the probability of large inundated areas and large inundation depths is also high (Borrero et al., 2006; Muhari et al., 2010, 2011).

C2 - EARTHQUAKE SCENARIO SELECTION: The authors must justify their choice as regards the magnitudes of the earthquake scenarios. Why a minimum Magnitude of 8.5 and not 8.25, for instance? Is a Mw8.25 earthquake causes a tsunami with no significant effect on the study area? Why do the authors not consider a maximum earthquake magnitude in the range of this of the 2004 Indian Ocean event (Mw9.2)? Such a choice would change the predicted tsunami inundation characteristics and therefore the associated evacuation plan.

Answer:

We used Mw 8.5 as the minimum scenario magnitude in our study because the tsunami hazard produced from the magnitudes less than this level, e.g. Mw 8.25 and Mw 8.0, are considered to be relatively small (below 1 m wave height in the coastal areas; McCloskey et al., 2008; Muhammad et al., 2016). From Figure 1 in this document, we see the relatively minor effects in Padang due to Mw 8.5 tsunami . It shows the tsunami wave heights at three stations, i.e. Tabing, Purus, and Teluk Bayur, at a depth of 5 m. The median wave heights produced from 100 tsunamigenic scenarios are about 1 m which is small and will have minor impact on land (see Muhammad et al., 2016). The impact becomes more insignificant if we consider the Mw 8.25 scenario. Therefore, we choose the Mw 8.5 as the minimum magnitude scenarios.

For the maximum scenarios (i.e. Mw 9.0), it was selected based on the existing research studies from geodetic, paleogeodetic, and paleotsunami investigations. These studies indicated that the accumulated slip in the Mentawai segment of the Sunda subduction zone may generate the tsunamigenic earthquake with the magnitude ranging from Mw 8.8 to Mw 9.0 (Zachariasen et al., 1999; Natawidjaja et al., 2006; Sieh et al., 2008). We did not consider a extreme scenario like the 2004 Indian Ocean tsunami (which is very long) because the tsunami sediment records in North of Sumatra indicated that the recurrence time of destructive tsunamis from the Aceh-Andaman sources is at least 600 years in comparison to ∼200 years for the Mentawai segment (Natawidjaja et al., 2006; Monecke et al., 2008) and hence, the Mw 9.0 consider to be more likely than the scenarios such as the 2004 Indian Ocean tsunami. However, such long ruptures are a possibility in the Mentawai segment – we simply did not consider such an assumption.

Based on Reviewer's recommendations, we have added to the methodology section of the revised manuscript the following descriptions regarding the choice of our magnitude scenarios in the revised manucript as follows:

The use of magnitude Mw 8.5 as the minimum scenario is because the tsunami hazard produced from the magnitude below this level, e.g. Mw 8.25 and Mw 8.0 is relatively small (below 1 m wave height in the coastal areas; see Muhammad et al., 2016). The maximum magnitude scenario (Mw 9.0) is based on the recommendation from geodetic, paleogeodetic, and paleotsunami studies confirmed that the accumulated slip in the Mentawai segment of the Sunda subduction zone may generate the tsunamigenic earthquake with the magnitude range from Mw 8.8 to Mw 9.0 (Zachariasen et al., 1999; Natawidjaja et al., 2006; Sieh et al., 2008).

C3 - STOCHASTIC TSUNAMI SIMULATION: It is not clear in the text that the numerical model used in this study is a finite-difference code solving non-linear shallow water equations in the Cartesian coordinate system. Please clarify. Also, I suppose that the numerical tsunami code (Goto et al., 1997) was benchmarked and used to accurately simulate other tsunami events, thereby, the authors should mention some references on this. Which algorithm was used to track the shoreline movement and calculate the inundation? Is it the moving boundary algorithm (Liu et al., 1995)? Other?

Answer: Yes it is. We used a finite-difference code to numerically solve non-linear shallow water equations in the Cartesian coordinate system.

We have added several references to the revised manuscript regarding the implementation of Goto et al. (1997) model for tsunami simulation.

The algorithm to track the shoreline movement and calculate the inundation is using approximate moving boundary algorithm proposed by Iwasaki and Mano (1797).

To cover the recommendations from the reviewer, the following texts have been added into the revised manuscript:

A finite-difference method incorporating staggered leap-frog scheme is adopted to solve the governing equations (Goto et al., 1997). In addition, in Goto et al. (1997) code the moving boundary approach developed by Iwasako and Mano (1797) is used for inundation modelling. This method has been successfully used to run the tsunami simulation in several region including Padang, Indonesia, Mexico, and Japan (Muhari et al., 2010, 2011; Goda et al., 2014; Mori et al., 2017).

C4 - METHOD FOR THE DEVELOPMENT OF EVACUATION PLANS: The paper addresses the development of tsunami evacuation plans using high-resolution flood maps and compares the estimated inundation depths with the buildings heights to define the vertical evacuation shelters. In my opinion, a crucial component for the development of effective evacuation plans is missing in this approach. It consists of investigating the vulnerability of the coastal building located within the inundation zone, in particular, the buildings assessed as shelters. This must include an assessment of the buildings resistance capacity to a successive impact of both the earthquake and the tsunami. The study site is located within the co-seismic deformation area (Fig. 1 and 3) and, therefore, a Mw8.5-9.0 earthquake would cause a strong shaking that can have heavy damage on the coastal buildings and road network well before the arrival of the tsunami wave. This issue must be addressed for an effective planning of tsunami evacuation in Padang, Indonesia.

Answer:

Thank you very much for these valuable comments. We have re-assessed the vulnerability of tsunami evacuation shelters (TES) considering both seismic and tsunami loadings. A new section: Section 2.2. vulnerability assessment of tsunami evacuation shelters has been added in the methodology section of the revised manuscript to explain the shaking and tsunami vulnerability assessments. The results from these assessments are also included in the results and discussion section. To facilitate the communications with the editor and the reviewers, a summary of the TES vulnerability assessment procedure and the assessments results is detailed in the supplement file (i.e. NHESS-2017-75-suplement.pdf). It is an extensive response so the PDF attachment is needed.

C5 - RESULTS: The results of tsunami hazard assessment (inundation maps) are of good quality and reflect, On the other hand, results on evacuation plans must be re-assessed taking into account the comment #4.

C6 - DISCUSSION: The discussion must be reworked on the light of the new results and include the vulnerability of the shelters to a successive impact from the earthquake and then the tsunami. Answer C5 and C6:

We have incorporated the seismic and tsunami vulnerability assessment results to the results and discussion section of the revised manuscript.

Please also note the supplement to this comment:
https://www.nat-hazards-earth-syst-sci-discuss.net/nhess-2017-75/nhess-2017-75-AC1-supplement.pdf

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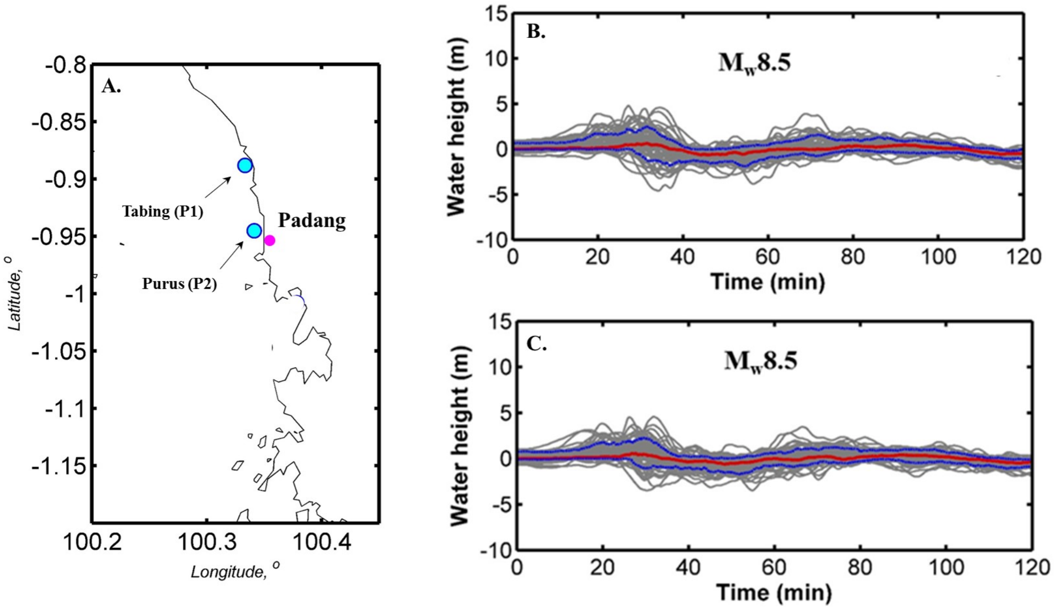

Fig. 1. Tsunami wave height profile near coastal line of Padang: (A) site location. (B). Tabing (P1) station). (C). Purus (P2) station.