The Neo-Deterministic Seismic Hazard map (NDSHA) of Sumatra compared with official 2010 and 2017 derived from PSHA method

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Abstract. Typical seismic hazard problem lies on determination of ground motion characteristics associated with future earthquakes. Strong ground motion characteristics such as Peak Ground Acceleration (PGA) is important information for engineers in order to provide earthquake resistant building. The Indonesian government has provided update of maps of PGA by released a series official PSHA (Probabilistic Seismic Hazard Assessment) maps in 1978, 2002, 2010 and 2017. On the other hand, the NDSHA (Neo-Deterministic Seismic Hazard Assessment) method has been developed and successfully applied to Sumatra. Because of the availability of numerical PGA data for the official PSHA 2010 and 2017, this paper discusses the comparison of PGA between derived from NDSHA and that of official PSHA updated in 2010 and 2017. The spatial resolution of the PGA digital map of PSHA is 0.01 degree and NDSHA is 0.1 degree. Due to the different resolution, a program and a script are developed to incorporate PSHA data into the NDSHA data points by performing interpolation procedure. The comparison results show the PGA of PSHA 2017 is significantly greater than PGA PSHA 2010. However, the PGA values of the 2017 PSHA map are lower than that of PSHA 2010 such as along the Sumatran fault in Central and South Sumatra. The PGA values estimated by using standard NDSHA with 10 Hz cut-off is higher than those of the computed PGA from PSHA at PE (Probability of Exceeding) of 2% in 50 year for official map released in 2010 and 2017. For comparison with PE of 2% in 50 year, the near field NDSHA gives the PGA value greater than that of the PSHA; and for the far field sources. This means the NDSHA calculation for Sumatra gives reasonable results based on the adopted magnitude distance threshold. This is due to the fact that the standard NDSHA is based on the realistic physical simulation of the seismic wave propagation. The comparison between the PGA computed based on the proposed enhanced version of NDSHA and PSHA shows that the updated version gives the same values at near field and lower values at the far sites; whereas the standard one gives a higher value in NDSHA, which in turn gives a higher PGA value for the near and far field sources.

1. Introduction
Possible magnitudes and impacts of earthquakes in an area are among unanswered questions for geoscientists. Meanwhile, we have to construct earthquake-resistant buildings on earth where we live. The earthquake experts in Indonesia have attempted to produce official seismic hazard maps. In 1983, the initial seismic hazard map formally adopted by the Indonesian government which is published in a
book titled “Peta Hazard Gempa Indonesia dalam Peraturan Perencanaan Tahan Gempa Indonesia untuk Gedung 1983” or Indonesian Earthquake Hazard Map in Earthquake resistant building planning 1983. The map classified the 8 levels of seismic hazard zone which based on the work of Beca and Ferner [1]. In 2002 the Ministry of Public Works issued a revised earthquake hazard map based on the calculation of PSHA (Probabilistic Seismic Hazard Assessment) [2]. Following the 2004 earthquake and tsunami, the government carried out further studies to anticipate future destructive earthquake by releasing new seismic hazard map in 2010 [3] [4] which included the new study of active Great Sumatra Faults (GSF) system [5] [6] [7]. After 5 years of the publication of the 2010 earthquake hazard map, there were several earthquakes occurred in the previously considered safe area therefore the government plan to issue and update the seismic hazard map in 2016. However, it was surprising that the Pidie Jaya earthquake [8] on December 7, 2016 which was destructive and took many casualties occurred in areas that had not been defined as active fault zones previously. Based on these events, the team needs to evaluate to include more detailed active fault map and the release of the new map was delayed until mid-2017 [9]. The official earthquake map issued by the Indonesian government in 2010 and 2017 uses the PSHA procedure as shown in figure 1a. The PSHA estimate the strong ground motion from GMPE (Gound Motion Prediction Equation) [10] [11] [12] [13]. On the other hand, the NDSHA method has been developed and applied in several countries [14] [15] with the procedure shown in Figure 1b. The NDSHA calculate the strong ground motion from synthetic seismogram [14] [16]. The technique for producing the synthetic seismogram has been verified with field observation of BMKG accelerometer and it’s respond spectral [17]. The seismic hazard maps have a PGA map, so it is interesting to investigate the difference in PGA values among the three maps discussed in this paper.

2. Methods

The discussion of this paper only focuses on the comparison of the PGA maps in Sumatra. Therefore, there is no complicated computing process but the numerical data in map form is used. The software used to manage and visualize the data into map form, as well as results on the comparison.

2.1 Numerical Map of PGA Data

To difference of the PGA values generally can be noticed by comparing two or more maps visually. However, the visual comparison has limitation due to the limited number associated with number is known. By using numerical comparisons the difference of the PGA values can be calculated more accurately because it directly compares the values of each related point. Therefore, this study requires
seismic hazard map information in the form of text format containing latitude, longitude, and PGA values.

As discussed above, there are several official maps of PSHA 1983 [19] [2], 2010 and 2017. However, the 1983 and 2002 PSHA maps are only available in the form of images of pdf. Fortunately, numerical data of official maps of PSHA 2010 and 2017 were obtained. The PSHA 2010 data is obtained from Fauzi Usamah in 2012 and the PSHA 2017 data was obtained from M. Asrurifak in the framework of research collaboration in 2018. Both numeric maps have been replotted as shown in Figure 2b and Figure 2c for PSHA 2017 and 2010, respectively. The maps are in accordance with the image map in the official book of earthquake hazard. Actually, for the PSHA map, we have more than one PE (possibility of exceeding) PGA maps, such as PE of 2% and 10% in 50 years. However, we limit the discussion to the PSHA map with a PE of 2% in 50 years. Other than comparing PSHA map released in different years, comparisons with other methods such as NDSHA were also carried out as shown in Figure 2a. NDSHA numerical data was obtained from the results of studies at the University of Trieste in 2016.

**Figure 2.** PGA maps that compared each other in this paper and the results of the plotting are shown in:

(a) The PGA NDSHA map plotted using points. Each point represents a PGA value obtained from many realistic simulation models of synthetic seismograms.

(b) Map of PGA PSHA 2017 which is officially issued by PuSGeN in the form of the book “Peta Sumber dan Bahaya Gempa Indonesia Tahun 2017”

(c) Results of the 2010 PSHA of Sumatra are officially issued by *Tim Revisi Peta Gempa (TIM 9).*
2.2 Software and Tools

Most researchers use proprietary software with friendly GUI facilities. However, we concern to copyright, we prefer to use open source software. We performed the whole procedure in Linux Ubuntu 16.04 operating system which is equipped with various other support tools from GNU. Final plotting process is by using GMT software [20]. All works use bash shell-based scripts so that automation processes can be perform in input, process, and output. The aim of the script is to simplify routine data processing for certain data format and the script that is created still allows settings through passing parameters. Following command was used to produce image 2a.

```
haz2map.sh -Caccg.cpt -rel -z0.23 shta9nf2res.fin -sub sunda3.gmt north.sh ESUP.ps diff.lab -tno -bWeSn -Gblue diff.lab -png
```

PGA data from PSHA has a relatively higher resolution of 0.01 degree compared to the PGA data obtained from NDSHA (only has 0.1 degree resolution). The PSHA procedure calculates the PGA by using GMPE so that it does not require long computing time even for very dense observation points. Meanwhile for NDSHA, PGA value is calculated based on realistic physical seismic wave propagation that is high computational cost so that the point is made relatively less dense in order to avoid long computational time. Due to the different resolution between NDSHA and PSHA, a program is created to interpolate PSHA point to point NDSHA that can be compared between one to another. The interpolation program was made by using Gfortran [21].

2.3 Comparison Schematics

Each version of the earthquake map, the PSHA 2010, the PSHA 2017 and the NDSHA, produces many different parameters for different purposes. For example for PSHA, one produced maps for PE of 2% and 10% for 50 years. Comparing all existing maps produce multiple differential maps and is more complicated to discuss. For NDSHA which is not a probability base, we only produces one map with MCE Input. Therefore, 3 maps were selected to be compared as shown in Figure 3 and labelled as the corresponding images. The comparison procedure of PGA maps is represented by a line that connects the PGA map which produces 4 lines (Figure 3). Especially for differences in PSHA 2017-2010, two maps were prepared differently. While the NDSHA comparison with PSHA 2010 and PSHA 2017 uses point plotting style mapping because it follows the lowest map resolution.

![Figure 3. Schematics of comparison PGA and associated figure discussed in this paper](image)

3. Results and Discussion

3.1 The Different 2017 to 2010 Official PSHA

The discussion is starting from official PGA PSHA for different updated times in 2017 and in 2010 with 2% PE in 50 year as shown in Figure 4. The PGA for PE of 10% in 50 years is not discussed and PGA value which is smaller than PGA for PE of 2% in 50 year. In view of the worst scenario side, it is better to discuss the PGA for PE of 2% in 50 years. In figure 4, the PGA PSHA 2017 seems to be larger than the 2010 PGA PSHA except for several spots such as the central part of Sumatran fault and the central part and the southern part of Sumatra. Likewise, with the archipelago in the forearc section,
there has been an increase in PGA. There is also an increase of PGA values in the Bangka Island which had been considered as a seismically safe zone. The increase in PGA is very significant in the northern Sumatra fault in the province of Aceh.

![Figure 4](image1.png)  
(a) area plotting style  
(b) point plotting style

Figure 4. The differential map of PGA from official PSHA map 2017 and 2010 with (a) area plotting style (b) point plotting style

![Figure 5](image2.png)  
(a) NDSHA – PSHA 2010  
(b) NDSHA – PSHA 2017

Figure 5. The differential map of PGA of NDSHA with official PSHA map for (a) 2010 (b) 2017

3.2 The Different NDSHA to 2017 and 2010 Official PSHA

The second part of the discussion is the comparison among different methods. The PGA NDSHA was compared to those of PSHA 2010 and PSHA 2017 for PE of 2% in 50year shown in Figure 5a and 5b, respectively. In general, the PGA NDSHA value is greater than the both PGA of the 2010 and the 2017 PSHA for the location close to Sumatran fault and smaller to areas far from the Sumatran fault.
This can be interpreted that the NDSHA PGA value is attenuated significantly in distance compared to the PSHA PGA values. Both differential maps, 2010 update map (figure 5a) and 2017 updated maps (figure 5b), visually look similar in the same the scale bar. The only different area is around Lake Toba. For the Banda Aceh city, the value of PSHA PGA is higher than the value provided by NDSHA for both differential maps.

4. Conclusion
The value of the 2017 PGA PSHA is greater than the 2010 PGA PSHA except for a number of spots such as in the central part of the Sumatran fault and the central and southern part of Sumatra. Significant increase of the PGA occurs in the Sumatra fault which is in the northern part of the province, precisely. The NDSHA PGA value is greater than the PSHA PGA, especially those close to the Sumatran fault, which is valid for areas far from the Sumatran fault, which can be interpreted as NDSHA is dampened more quickly by increasing distance compared to the PGA PSHA values. On the other hand, this shows that the NDSHA method provides more realistic results than the PSHA method because the calculation of PGA is based on realistic physics simulation of the seismic wave propagation were close to the fault will have a very large PGA compared to PGA produced by areas far from the sources.

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