The Sensitivity of Maximum Magnitude Range Parameter in Bedrock Acceleration Calculation for 2500 Years of Return Period, Case Study: Bengkulu Province, Indonesia

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Abstract. Infrastructure development such as multi-storey buildings, toll roads, bridges, housing, and others continue to be carried out to improve the economic region. Those things require planning and a good foundation in order to have a durable and earthquake-resistant building. Earthquake is one of the most destructive geological hazards and can trigger other geological hazards, such as landslides, tsunamis, liquefaction, and land subsidence. Bengkulu Province, Indonesia, is one of the susceptible areas to this hazard. The earthquake hazard assessment is important to do to reduce the risk of material and immaterial loss. This study aims to determine the sensitivity of the maximum magnitude range parameter using the probabilistic seismic hazard analysis (PSHA) method using USGS PSHA software. The result obtained from this study were in Bengkulu Province with all earthquake sources show the value of bedrock acceleration with 2500 years of return period in the range 1.2 – 1.5g. The observed sensitivity shows that Bengkulu Province has a sensitivity value in range of 0.01 – 0.03 with the highest value being in Bengkulu City with a value (0.02722) due to uncertainties of maximum magnitude with range of (+0.1) Mw and the fault source indicates that Lebong has a value of (0,05890742).

1. Introduction
The island of Sumatra, within the Indonesian archipelago, sits a top the Southeast Asian plate, which overrides the subducting Australian and Indian plates [1] and also known as Sumatra Subduction Zone, frequently triggers earthquakes in western part of Sumatra [2]. The occurrence of earthquakes in the Sumatra region is controlled mainly by the north-northeast oriented convergence of the Indian-Australian lithospheric plate toward the Sunda plate [3]. In addition, the other tectonic activities that can cause seismicity are the Sumatra Fault Zone (SFZ) that extend across the Sumatran island. However, most earthquake occur in subduction zone which are estimated be around 60 mm/years, such as Great Sumatra (Mw = 9.1) 2004, Nias (Mw = 8.7) 2005, Padang (Mw = 7.6) 2009 dan Bengkulu (Mw = 8.4) 12 September 2007 [4–6].

Bengkulu Province, Indonesia, is one of the susceptible earthquake areas. An earthquake that occurred in Bengkulu can trigger the other geological hazard such as the earthquake on September 12, 2007 with a magnitude (Mw = 8.4) which had the potential for liquefaction [7]. Because of the other potential hazards, it is necessary to conduct soil vulnerability research in order to identify and reduce risks from earthquake events, which is soil velocity on the ground surface [8]. The earthquake hazard
assessment is important to do to reduce the risk of material and immaterial loss. In addition, the concept of earthquake resistant building is very important in reducing the seismic hazard [9].

This study aims to calculate the level of bedrock shaking and to determine the sensitivity of the maximum magnitude range parameter using the PSHA (Probabilistic Seismic Hazard Analysis) method. The earthquake source model and each program used include (1) fault earthquake source processed with USGS PSHA program through fltrate and hazFXnga7c modules, (2) background earthquake source processed with agridMLsm, and hazgridXnga2 modules, (3) megathrust earthquake source processed with hazSUBXnga module. The result of all earthquake sources, it calculated with hazallXL program [10].

2. Methodology
In conducting a seismic hazard assessment, a complete earthquake historical data is required. So that an area can be predicted the potential hazard that will occur. Only earthquake data with a radius of 500 km from boundary of Bengkulu Province were analyzed. The data used in this study is based on the catalog of National Seismic Center (PuSGeN) 2017 which can be seen in Figure 1.

The next stage is to identify the source of the earthquake. Earthquake sources that will be included in the USGS PSHA module are grouped into three, namely: fault earthquake source, background earthquake source (shallow and deep) and subduction earthquake source (megathrust). The minimum magnitude scale used in the earthquake fault source and subduction (megathrust) mechanism is 6.5Mw. For shallow background earthquake source data ranges from 4.5 <Mw <6.5 and for deep background earthquake sources it is limited to > 4.5 Mw. All parameters are shown in Tables 1 and 2.

All data and parameters will be processed using USGS PSHA. The software consists of several modules that will process each earthquake source data, including (1) fault earthquake source processed with the fltrate and hazFXnga7c modules, (2) background earthquake source processed with the agridMLsm and hazgridXnga2 modules, (3) megathrust earthquake source processed with the hazSUBXnga module. The results of all earthquake sources are calculated with the hazallXL program. This probabilistic seismic hazard analysis (PSHA) was conducted to recommend the peak ground acceleration rate (PGA) in bedrock, as a function of the possible earthquake hazard level [4]. The important points of PSHA are to identify errors, input parameters, run the module based on the return period, define the logic tree and GMPE.
The final result of this earthquake hazard analysis is a peak ground acceleration map in the bedrock of study area with a 2% chance of an earthquake occurring in 50 years (return period of 2500 years).

### Table 1. Megathrust earthquake source

| Index | Structure Name            | Segment     | a value | b value | Maximum Magnitude |
|-------|---------------------------|-------------|---------|---------|-------------------|
| M2    | Sumatran Megathrust       | Nias-Simelue| 4.48    | 0.88    | 8.9               |
| M3    | Sumatran Megathrust       | Batu        | 4.59    | 0.89    | 8.2               |
| M4    | Sumatran Megathrust       | Mentawai-Siberut | 4.25 | 0.85 | 8.7               |
| M5    | Sumatran Megathrust       | Mentawai-Pagai | 3.02 | 0.63 | 8.9               |
| M6    | Sumatran Megathrust       | Enggano     | 5.57    | 1.05    | 8.8               |
| M7    | Sunda-Strait Megathrust   | Selat Sunda | 5.99    | 1.15    | 8.8               |
| M8    | Java Megathrust           | West-Central Java | 5.55 | 1.08 | 8.8               |

In this study, there are 7 subduction segments that can affect the probability of seismic hazard occurrences in Bengkulu. In addition to the subduction segments, the data used to analysis the subduction earthquake source contains a-b value and maximum magnitude (Table 1). The a-b value mean the data is prepared to be processed using hazSUBXnga module. The a-b value is the seismic parameter at each earthquake source which correlates with the incidence rate per year and the comparison of the occurrence of earthquake events at several magnitudes studied. On the other hand, the Mmax value is the potential magnitude that will occur if the entire earthquake structure moves.
| ID | Structure Name                | Slip-Rate mm/yr | SM<sup>a</sup> | L (Km) | Dip (Km) | Top (Km) | Bottom (Km) | Mmax<sup>b</sup> (Mw) |
|----|------------------------------|-----------------|----------------|--------|----------|----------|-------------|-----------------------|
| 29 | Sumatran Fault Renun-A       | 10.5            | SS             | 180    | 90       | 3        | 20          | 7.7                   |
| 32 | Sumatran Fault Toru          | 11.5            | SS             | 95     | 90       | 3        | 20          | 7.4                   |
| 33 | Sumatran Fault Angkola       | 6.0             | SS             | 160    | 90       | 3        | 20          | 7.7                   |
| 34 | Sumatran Fault Barumun       | 6.5             | SS             | 125    | 90       | 3        | 20          | 7.5                   |
| 35 | Sumatran Fault Sumpur        | 14.0            | SS             | 35     | 90       | 3        | 20          | 6.9                   |
| 36 | Sumatran Fault Sianok        | 14.0            | SS             | 90     | 90       | 3        | 20          | 7.4                   |
| 37 | Sumatran Fault Sumani        | 14.0            | SS             | 60     | 90       | 3        | 20          | 7.1                   |
| 38 | Sumatran Fault Suliti        | 14.0            | SS             | 95     | 90       | 3        | 20          | 7.4                   |
| 39 | Sumatran Fault Siulak        | 14.0            | SS             | 70     | 90       | 3        | 20          | 7.2                   |
| 40 | Sumatran Fault Dikit         | 12.0            | SS             | 60     | 90       | 3        | 20          | 7.1                   |
| 41 | Sumatran Fault Ketaun        | 12.0            | SS             | 85     | 90       | 3        | 20          | 7.3                   |
| 42 | Sumatran Fault Musi          | 13.5            | SS             | 70     | 90       | 3        | 20          | 7.2                   |
| 43 | Sumatran Fault Manna         | 13.5            | SS             | 85     | 90       | 3        | 20          | 7.3                   |
| 44 | Sumatran Fault Kumering-North| 12.5            | SS             | 111    | 90       | 3        | 20          | 7.5                   |
| 45 | Sumatran Fault Kumering-South| 12.5            | SS             | 60     | 90       | 3        | 20          | 7.1                   |
| 46 | Sumatran Fault Semangko Barat-A| 8.0            | SS             | 90     | 90       | 3        | 20          | 7.4                   |
| 47 | Sumatran Fault Semangko Barat-B| 8.0            | SS             | 80     | 90       | 3        | 20          | 7.3                   |
| 49 | Sumatran Fault Semangko Timur-A| 5.0             | SS             | 12     | 90       | 3        | 20          | 6.5                   |
| 50 | Sumatran Fault Semangko Timur-B| 3.0             | SS             | 35     | 90       | 3        | 20          | 6.9                   |
| 51 | Sumatran Fault Semangko Graben| 3.0             | N              | 50     | 90       | 3        | 20          | 6.5                   |
| 52 | Sumatran Fault Ujung Kulon A| 10.0            | SS             | 80     | 90       | 3        | 20          | 7.3                   |
| 53 | Sumatran Fault Ujung Kulon B| 10.0            | SS             | 150    | 90       | 3        | 20          | 7.6                   |
| 54 | Mentawai Fault Mentawai     | 5.0             | RS             | 560    | 45W      | 3        | 20          | 8.2                   |
| 55 | Mentawai Fault Enggano       | 5.0             | RS             | 160    | 45W      | 3        | 20          | 6.5                   |
| 1  | Cimandiri Fault Cimandiri    | 0.55            | RS             | 23     | 45S      | 3        | 18          | 6.7                   |
| 2  | Cimandiri Fault Nyalindung-Cibeber| 0.4            | RS             | 30     | 45S      | 3        | 18          | 6.5                   |
| 3  | Cimandiri Fault Rajamandala  | 0.1             | SS             | 45     | 90       | 3        | 18          | 6.6                   |
| 4  | Lembang Fault Lembang        | 2.0             | SS             | 29.5   | 90       | 3        | 18          | 6.8                   |
| 5  | Baribis-Kendeng Fold-ThrustZone Subang | 0.1            | RS             | 33     | 45S      | 3        | 18          | 6.6                   |

<sup>a</sup> SM = Sense Mechanism, SS = Strike-Slip, N = Normal, RS = Reverse-Slip  
<sup>b</sup> Mmax = Maximum Magnitude
For the data used to analysis the fault earthquake source, there are 29 fault segments, slip rate, sense mechanism, length, dip, top, bottom, and maximum magnitude (Table 2). Input and running the data with the fltrate module. The output file of the fltrate module, add the GMPE parameter and continue the analysis with the hazFXnga7c module.

Logic tree can be used to address the statistical uncertainties in the major elements of seismic source characterization [11]. The logic tree allows a formal characterization of uncertainty in the analysis by including alternative interpretations, models, and parameters that are weighted in the analysis according to their probability of being correct [12]. The weighting of the logic tree can be seen in the Figure 2.

Still not yet specific GMPE for the Indonesian region, therefore GMPE from other regions that have the same tectonics will be applied to Indonesia. The selection of GMPEs was based on seismotectonic conditions, which are generally categorized into shallow crustal (used for crustal fault and shallow background sources), subduction interface, and intraslab (Wadati–Benioff zone) for deep background sources [5]. The GMPE used in this study is shown in the Figure 2.

![Logic tree used for all sources with weighted for all of earthquake sources models](image)

**Figure 2.** Logic tree used for all sources with weighted for all of earthquake sources models

Gutenberg Richter types for fault and background earthquake sources of 0.66 and 0.34. Meanwhile, the subduction earthquake source was 0.50. The maximum magnitude used in this study, with a range of (+0.1) Mw and different attenuation function for each source (Figure 2). After identifying all earthquake sources and analyzing them using each module, the next step is to add up all the outputs using the hazallXI program. So the results can be read properly.
3. Result and Discussion

Based on PSHA analysis, the results obtained are displayed in the form of a PGA map for each earthquake source and a combination of all earthquake sources which are presented in Figure 3. The resulting PGA value will increase if the area is close to the earthquake source. The fault area shows that the PGA value range 1.2 – 1.5g on the East of Bengkulu. It can be correlated that the location of the fault earthquake source is that area, so the resulting PGA value is greater than the Southwest of Bengkulu (Figure 3a). As well as with subduction (megathrust) area, the PGA value is increasing to the west with the proximity of the subduction zone location (Figure 3b). Different of the background area show a relatively small PGA value to the other earthquake area (Figure 3c). All of the earthquake sources combined, it will look like Figure 3d which shows that the higher PGA values are near to the subduction and fault areas. If the resulting map is compared with the result in book of Indonesia earthquake source in 2017, so this map (Figure 3d) shows the PGA value is (1.2 – 1.5g) higher than national earthquake map (1.0 – 1.2g) [13]. In addition, the researchers also compared the results with those obtained in the study by having a peak ground acceleration value of (0.36 gal to 1.35 gal) [14].

![PGA Map](image-url)
This study also discusses how the maximum magnitude sensitivity level in fault and subduction areas. In contrast to other area, sensitivity is not performed on the background area because in this method (using USGS PSHA), uncertainties of maximum magnitude can’t be modified as other mechanism. It can be seen in Figure 3, the random sampling location points for sensitivity are shown.
There are 10 location points by taking randomly in each region in Bengkulu Province. As seen in Table 3, there are three different Mmax results. To get these results, by analyzing the fault earthquake source described in the previous chapter. Then, with the same steps but with the Mmax in each segment (-0.1) and (+0.1) Mw. Therefore, the three Mmax results obtained were analyzed using standard deviation to determine the sensitivity level of the earthquake source.
Based on the results obtained from Table 3, it is made in the form of a graphics as shown in Figure 4, showing that Lebong District have dominant value of (0.05890742).

**Table 4.** Data of subduction sensitivity analysis

| Location Number | Bengkulu Province | X     | Y     | Mmax (-0.1)   | Mmax (+0.1) | Standard Deviation |
|-----------------|-------------------|-------|-------|---------------|-------------|--------------------|
| 1               | Kota Bengkulu     | 102.3 | -3.8  | 0.87432       | 0.90235     | 0.92885            |
|                 |                   |       |       | 0.027269      |             |                    |
| 2               | Bengkulu Utara    | 101.9 | -3.3  | 0.90314       | 0.92871     | 0.95317            |
|                 |                   |       |       | 0.025017      |             |                    |
| 3               | Bengkulu Tengah   | 102.4 | -3.7  | 0.75418       | 0.78115     | 0.80259            |
|                 |                   |       |       | 0.024258      |             |                    |
| 4               | Bengkulu Selatan  | 102.9 | -4.4  | 0.58603       | 0.60439     | 0.62198            |
|                 |                   |       |       | 0.017976      |             |                    |
| 5               | Lebong            | 102.1 | -2.9  | 0.57365       | 0.59102     | 0.60806            |
|                 |                   |       |       | 0.017205      |             |                    |
| 6               | Rejang Lebong     | 102.9 | -3.4  | 0.40398       | 0.41735     | 0.43049            |
|                 |                   |       |       | 0.013255      |             |                    |
| 7               | Kepahiang         | 102.7 | -3.7  | 0.57213       | 0.59175     | 0.61071            |
|                 |                   |       |       | 0.019291      |             |                    |
| 8               | Muko-Muko         | 101.3 | -2.5  | 0.89201       | 0.9193      | 0.94531            |
|                 |                   |       |       | 0.026653      |             |                    |
| 9               | Seluma            | 102.6 | -4    | 0.74234       | 0.77234     | 0.79655            |
|                 |                   |       |       | 0.027156      |             |                    |
| 10              | Kaur              | 103.5 | -4.6  | 0.35928       | 0.37002     | 0.38036            |
|                 |                   |       |       | 0.010541      |             |                    |

Furthermore, analysis is also carried out on the subduction earthquake source with the same method as obtaining the standard deviation value for the previous fault earthquake source. The results obtained show that the standard deviation is in the range 0.010 – 0.027 (Table 4).
The graphic shows that the highest deviation value (which also represents the highest sensitivity) is in Bengkulu City. In addition, if the point is located near the center of the subduction segment (megathrust), it will produce a higher acceleration than any other point close to the source.

4. Conclusion
The result obtained from this study were in Bengkulu Province with all earthquake sources show the PGA value in the range 1.2 – 1.5g. It can be seen that the fault and subduction (megathrust) earthquake source have a significant value than the background earthquake source. All values of sensitivity were based on subduction (megathrust) and fault mechanism. The observed sensitivity of the subduction mechanism (megathrust) indicates that Bengkulu City has a value (0.027269) due to the uncertainty of the maximum magnitude with the range (±0.1) Mw. Meanwhile, the sensitivity of the fault source indicates that Lebong has a value of (0.0589074).

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