Indonesian Geotechnical Journal, April 2022, Vol 1 (1). Page 58-68
DOI: https://doi.org/10.56144/igj.v1i1.8
E-ISSN 2829-7520
https://indonesian-geotechnical-journal.org/index.php/JGI/issue/archive

Making PGA Hazard Curve in Big Cities of Bengkulu by Using USGS PSHA Modified

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SUBMITTED 9 April 2022 **REVISED** 19 April 2022 **ACCEPTED** 25 April 2022

ABSTRACT The tectonic plate movement that limits the Indonesian territory causes frequent earthquakes because the plates have dynamic rocks properties with varying strengths. The collision of the plates causes fault zones, such as in Bengkulu, a region traversed by the Sumatran fault with a record of many earthquakes. The rapid growth and development of technology could support increased infrastructure development by considering earthquakes a major global hazard. Therefore, this study aimed to create a PGA hazard curve useful in improving infrastructure development in Bengkulu's big cities. Data were sourced from the Book of Indonesian Earthquake Hazard and Source 2017. The United States Geological States Probabilistic Seismic Hazard Analysis (USGS PSHA) software was modified regarding the Ground Motion Prediction Equation (GMPE) database. The GMPE used in this study are (1) BC Hydro (2012) updated for subduction source; (2) Campbel Bozorgnia (2014), Boore Atkinson (2014) and Chiou Young (2014) for shallow crustal source, and (3) Zhao et al. (2006) and Abrahamson et al. (2018) for intraslab, with 500, 1,000, 2,500, 5,000, and 10,000 years return periods. The results obtained using the new GMPE showed a change in the maximum acceleration. The Hazard Curve (HC) and PGA map showed that the Kepahiang and Lebong Districts have the highest PGA values of 1.8070 and 1.8433 g, respectively, for the 10,000 year return period. The lowest value was 0.297g recorded in Rejang Lebong for 500 year return period.

KEYWORDS Earthquake; Bengkulu; GMPE; PGA Hazard Curve

1 INTRODUCTION

Indonesia is highly prone to seismic activity because it is located at the confluence of the India-Australia, Eurasian, Pacific, and Karolina-Philippine plates (Natawidjaja, 2021). The tectonic plate's movement limiting its territory has dynamic movements, causing frequent geological disasters, such as earthquakes, as depicted in Figure 1. Earthquake is a major destructive geological hazard that triggers landslides, tsunamis, liquefaction, and land subsidence (Azwar et al., 2021; McCaffrey, 2009). Over the past 15 years, Indonesia has experienced 14 earthquakes of Mw 7.5 or above. These include the 2004 Mw 9.1 Great Sumatra, 2005 Mw 8.7 Nias, 2009 Mw 7.6 Padang, 2018 Mw 7.5 Palu earthquakes (Irsyam et al., 2020), and October 25, 2010, Mw 7.8 Mentawai (Lay et al., 2011).

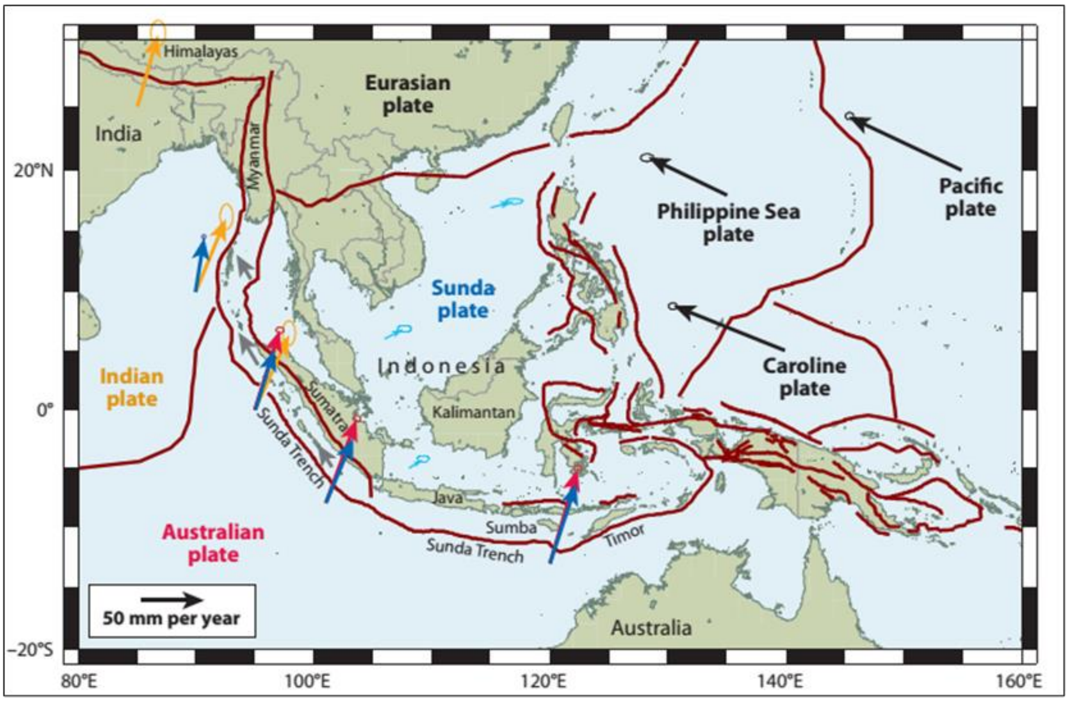

Figure 1. Seismotectonic in Indonesia (after McCaffrey, 2009).

Bengkulu city is located on Sumatra Island and has a high intensity of earthquakes, as shown in Figure 2. The source of the earthquakes is the subduction zone between the Indo-Australian and Eurasian plates and an active Sumatra Fault Zone crossing the island (Murtianto, 2016; PuSGeN, 2017). Bengkulu Province experienced a strong earthquake with a magnitude of 7.9 Mw on June 4, 2000, and another on September 12, 2007, with a magnitude of 8.6 Mw (Misliniyati et al., 2018). The last destructive earthquake on September 12, 2007, caused 14 deaths, 38 injuries, and damage to thousands of buildings (Supartoyo, 2007). Therefore, it is important to reduce the risk caused by earthquakes by conducting periodic probabilistic seismic hazard analyses in Bengkulu and surrounding areas to minimize casualties and material damage. This analysis is widely used to assess hazard risks for input into public and financial policies (Zhenming, 2006).

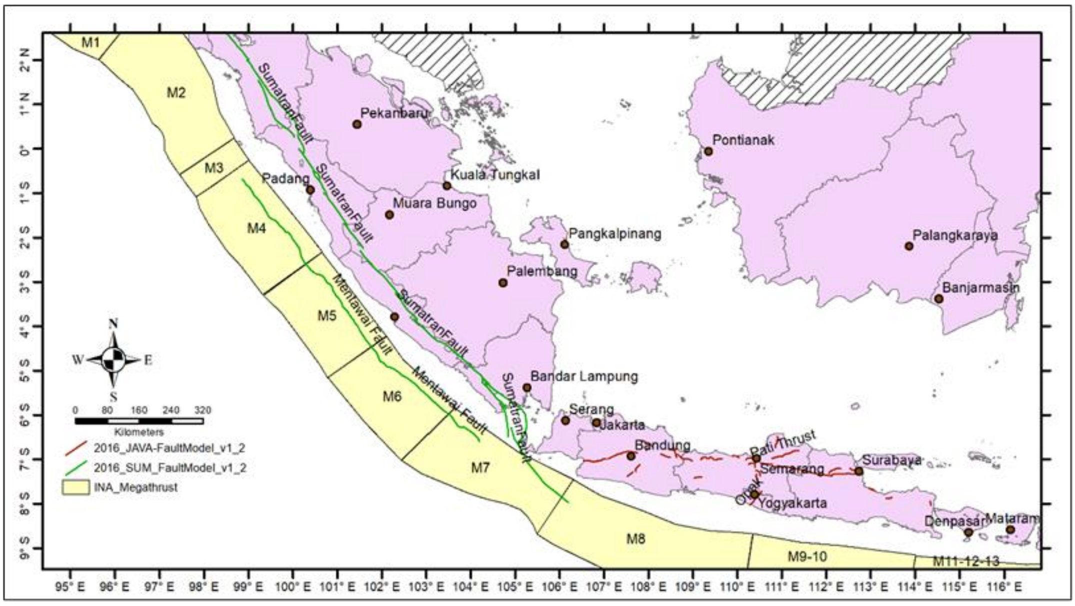

Figure 2. Seismotectonic around Bengkulu Province based on PuSGeN 2017.

Bengkulu Province comprises ten districts, each with the planning and authority for development. The increasing infrastructure development in the region necessitates information on the Hazard Curve (HC) of earthquake events. This is intended for an initial assessment to design earthquake-resistant infrastructure buildings. The hazard curve is a graph connecting the return period or the probability of earthquakes occurring per year with a certain acceleration spectral (Wang et al., 2003) and is often used in calculating seismic hazard analysis.

This study aimed to obtain a hazard curve in cities of the Bengkulu Province because no PGA hazard curve in Indonesia has adopted the relatively new GMPE. Therefore, this study conducted an earthquake hazard analysis with the new GMPE using the United States Geological States Probabilistic Seismic Hazard Analysis (USGS PSHA) software. The Ground Motion Prediction Equation (GMPE) used are BC Hydro (2012) updated for subduction source, Campbel Bozorgnia, (2014), Boore Atkinson (2014) and Chiou Young (2014) for shallow crustal source, and Zhao et al. (2006) also Abrahamson et al. (2018) for intraslab (Abrahamson et al., 2016, 2018; Boore et al., 2014; Campbell and Bozorgnia, 2014; Chiou and Youngs, 2014; Syahbana et al., 2020; Zhao et al., 2006).

2 METHODS

The first step in the seismic hazard analysis was collecting and processing earthquake data obtained from the 2017 National Earthquake Center Catalog (PuSGeN). The data were collected within a radius of 500 km from the Bengkulu Province boundary. Moreover, the three sources processed using the USGS PSHA were the fault, background or shallow and deep, and megathrust earthquake sources. The background earthquake source was divided into six depths, as mentioned in the National Indonesian Earthquake Map 2017. The depths are 0-25 km and 25-50 km for shallow background, and 50-100 km, 100-150 km, 150-200 km, 200-300 km for Benioff Zone or deep background (Irsyam et al., 2020; Syahbana et al., 2021) The minimum magnitude scale used in the source mechanism for faults and megathrust is 6.5 Mw. The background earthquake data were grouped into magnitude 4.5-6.5 Mw and 4.5-7.8 Mw for shallow background and Benioff Zone, respectively.

The USGS PSHA consists of several modules used to process each earthquake source mechanism. First, the filtrate and hazFXnga7c modules processed fault earthquake source data. Second, the agridMLsm and hazgridXnga modules processed background earthquake source data. Third, the hazSUBXnga module processed megathrust earthquake source data. After processing, the hazallXL module was used to determine the results of each earthquake source.

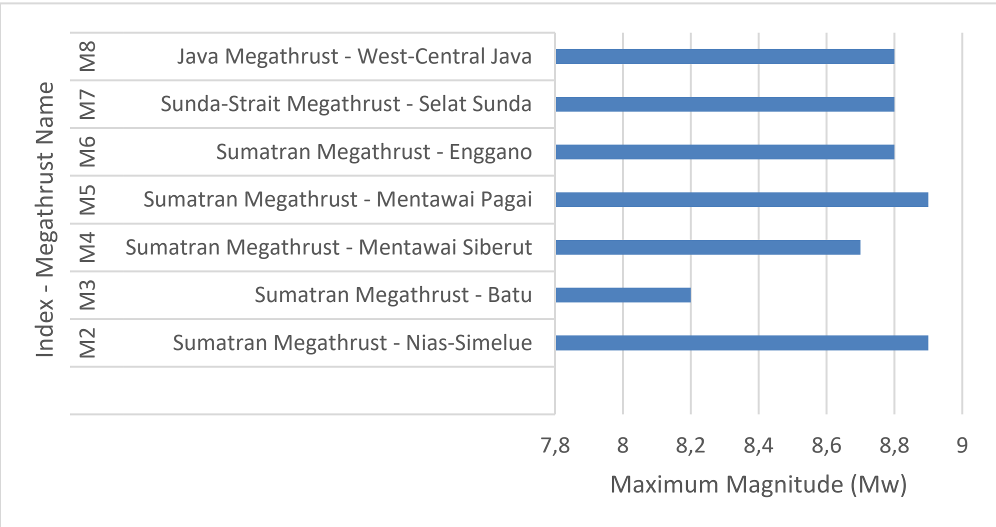

Figure 3. Megathrust earthquake source [Azwar et al., 2021].

There are 29 fault segments consisting of several data shown in Figure 4. Each fault segment data has an input file processed using the filtrate module. The resulting output file was added with GMPE parameters and analyzed using the hazFXnga7c module. In processing the background earthquake source data, input files were made with 0-50 km shallow depth limited to 4.5<Mw<6.5 and a 50-300 km depth limited to the range of 4.5<Mw<7.8. Completeness of data for background sources based on time windows and distance showed that the minimum number of years for 4.5<Mw<6 is 1964, for 6=<Mw<7 is 1954, and 1900 for >7 Mw. Moreover, megathrust earthquake sources have seven segments shown in Figure 3. Each with an input file comprising location data, GMPE, and magnitude, the segments were processed using hazSUBXnga. Figure 5 shows all the processes conducted using the logic tree.

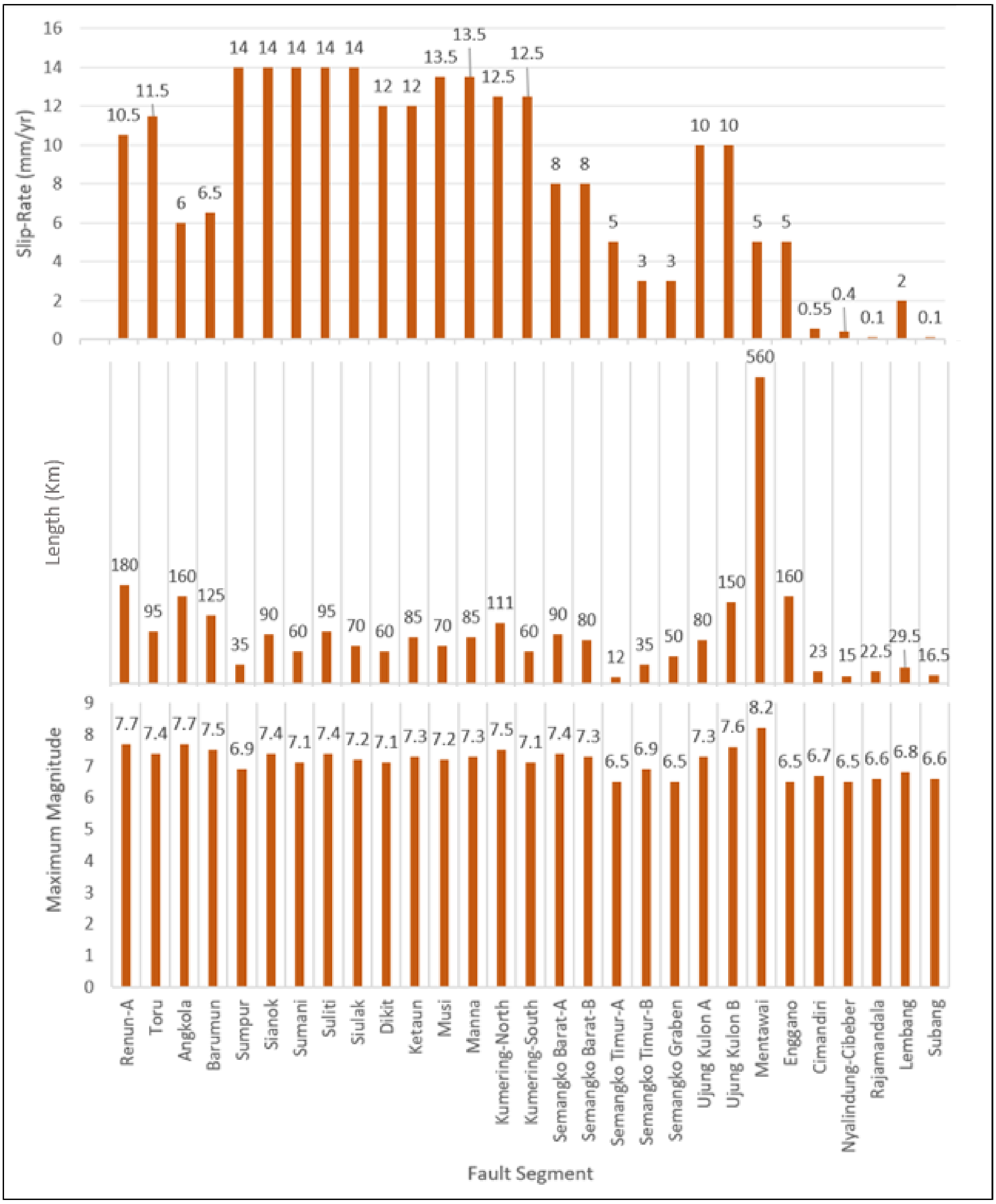

Figure 4. Fault earthquake source [Azwar et al., 2021].

Fault Model

Type	Characteristic	0.66
	Gutenberg Richter	0.34
Magnitude Uncertainty	Mmax -0.1	0.2
	Mmax	0.6
	Mmax +0.1	0.2
GMPE	Boore-Atkinson NGA 2014	0.33
	Campbell-Bozorgnia NGA 2014	0.33
	Chiou-Youngs NGA 2014	0.33

Subduction Model

Type	Characteristic	0.50
	Gutenberg Richter	0.50
Magnitude Uncertainty	Mmax -0.1	0.2
	Mmax	0.6
	Mmax +0.1	0.2
GMPE	BCHydro 2012updated	0.33
	Atkinson-Boore 2003	0.33
	Youngs 1997	0.33

Shallow Background Model

Type	Characteristic	0.66
	Gutenberg Richter	0.34
Magnitude Uncertainty	Strike Slip	0.33
	Reverse	0.33
	Normal	0.33
GMPE	Boore-Atkinson NGA 2014	0.33
	Campbell-Bozorgnia NGA 2014	0.33
	Chiou-Youngs NGA 2014	0.33

Deep Background Model

Type	Characteristic	0.66
	Gutenberg Richter	0.34
Magnitude Uncertainty	Strike Slip	0.33
	Reverse	0.33
	Normal	0.33
GMPE	Zhao 2006 intra	0.33
	Abrahamson 2018	0.33
	AB 2003 intraslab world	0.33

Figure 5. The logic tree was used for all sources and weighted for all earthquake sources models.

The return periods used in this study are 500, 1,000, 2,500, 5,000, and 10,000 years. This reoccurrence time is the structural design, such as high-rise buildings, bridges, offshores, and dams. Each return period was used when processing earthquake data sources using the hazallXL module.

3 RESULTS

The PSHA analysis in Bengkulu Province resulted in the five PGA maps shown in Figure 6a-6e. Figure 6a indicates a maximum acceleration (PGA) range of 0.8-0.9 g, increasing acceleration towards the fault. Among the big cities studied, Kepahiang District had the largest acceleration of 0.8033 g, while the lowest was 0.2973 recorded in eastern Rejang Lebong District.

Figure 6b shows a maximum acceleration (PGA) range of 1.2-1.5 g, increasing towards the fault. Kepahiang District had the largest acceleration of 1.0161 g, while the lowest was 0.3556 g recorded in eastern Rejang Lebong District.

Figure 6c exhibits a maximum acceleration (PGA) range of 1.5-2 g, increasing towards the fault. Kepahiang District had the largest acceleration of 1.3178 g, while the lowest was 0.4404 g recorded in eastern Rejang Lebong District.

In Figure 6d, the maximum acceleration (PGA) ranges between 1.5-2 g, indicating an increase towards the fault. The Lebong and eastern Rejang Lebong districts had the largest and lowest acceleration of 1.5831 g and 0.5101 g, respectively.

Figure 6e indicates a maximum acceleration (PGA) ranging between 2-2.5 g, increasing towards the fault. Similarly, the Lebong District and eastern Rejang Lebong districts had the largest and lowest acceleration of 1.8433 g and 0.5840 g, respectively.

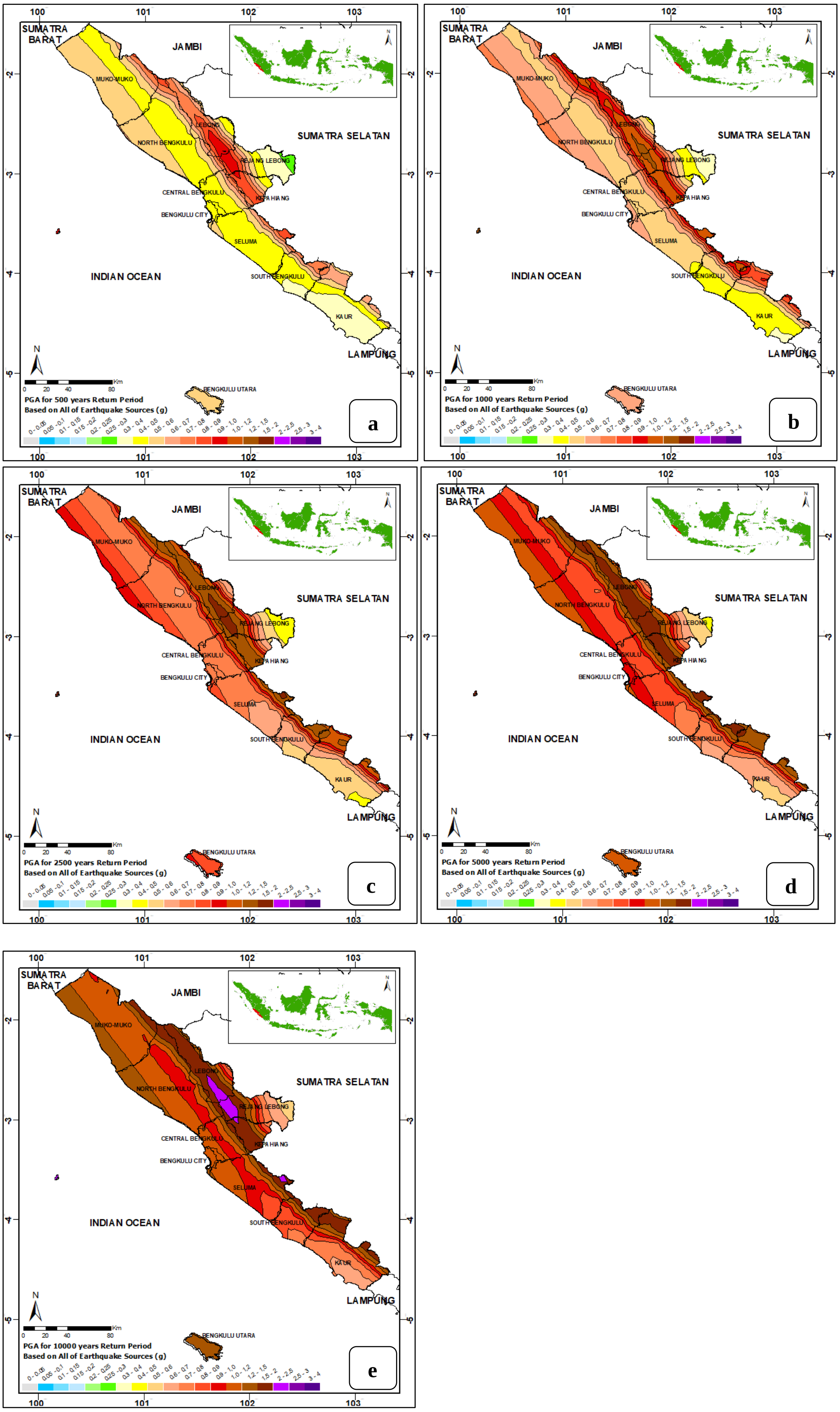

Figure 6. PGA Map in Bengkulu Province. 500 years return period (c), 1,000 years return period (d), 2,500 years return period (e), 5,000 years return period (f) and 10,000 years return period (g).

The hazard curve was made in every city in Bengkulu Province, as presented in Table 1. The resulting acceleration was chosen according to the coordinates selected randomly in each city. The five return periods used in this study are 500, 1,000, 2,500, 5,000, and 10,000 years. Figure 7 shows the hazard curve is shown.

Table 1. The rate for each city in Bengkulu Province

Name of City (longitude | latitude)	Rate (event/year)				
	0.1	0.05	0.02	0.01	0.005
Bengkulu City (102.3 | -3.80)	0.4894	0.6039	0.7846	0.9388	1.1162
North Bengkulu (101.9 | -3.30)	0.5119	0.6285	0.8115	0.9699	1.1442
Central Bengkulu (102.4 | -3.70)	0.4789	0.5813	0.7297	0.8528	0.9870
South Bengkulu (102.9 | -4.40)	0.3997	0.4783	0.5995	0.7008	0.8134
Lebong (102.1 | -2.90)	0.7666	0.9901	1.3141	1.5831	1.8433
Rejang Lebong (102.9 |-3.4)	0.2973	0.3556	0.4404	0.5101	0.5840
Kepahiang (102.7 | -3.70)	0.8033	1.0161	1.3178	1.5700	1.8070
Muko-Muko (101.3 | -2.50)	0.5054	0.6206	0.8013	0.9573	1.1317
Seluma (102.6 | -4.00)	0.4622	0.5644	0.7119	0.8385	0.9757
Kaur (103.5 | -4.60)	0.4282	0.5463	0.7165	0.8576	1.0105

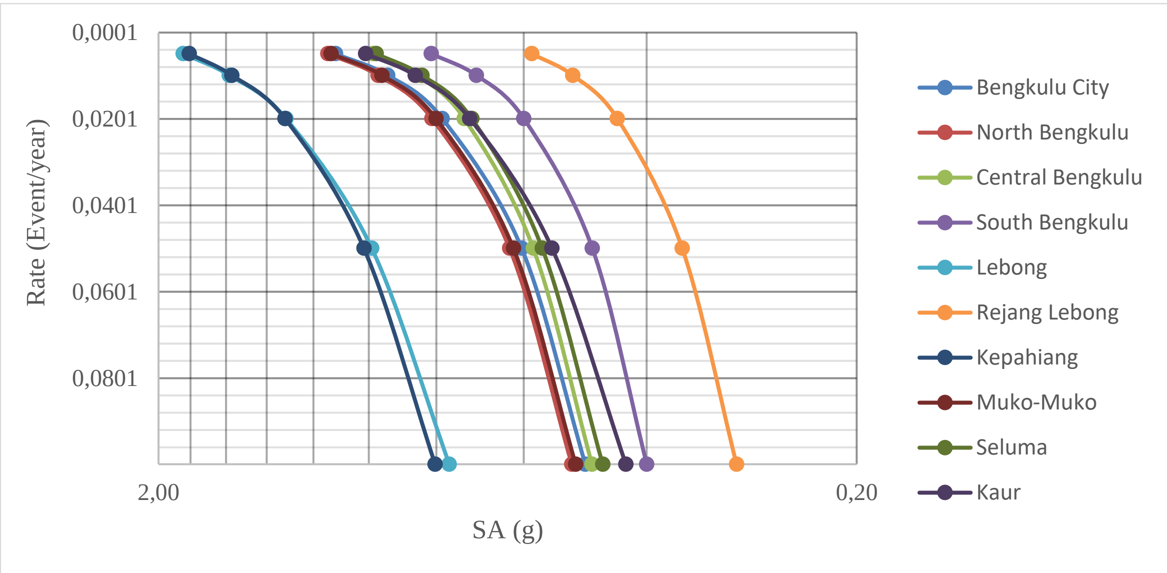

Figure 7. Hazard curve for each city in Bengkulu Province.

4 DISCUSSION

The hazard curve correlates the return period and the resulting spectral acceleration (Syahbana et al., 2020). This study used five repeat periods based on the earthquake source in Figure 7 to analyze ten cities, including Bengkulu City, North Bengkulu, Central Bengkulu, South Bengkulu, Lebong, Rejang Lebong, Kepahiang, Muko-Muko, Seluma, and Kaur.

Figure 7 shows that Kepahiang and Lebong districts had the highest acceleration among all the cities because they are closest to the Musi and Ketaun segments of the Sumatran faults. The acceleration values generated at the 500, 1,000, 2,500, 5,000, and 10,000 years return period for Kepahiang District are 0.8033, 1.0161, 1.3178, 1.5700, and 1.8070 g, respectively. In comparison, the acceleration values for Lebong District were 0.7666, 0.9901, 1.3141, 1.5831, and 1.8433g generated at the same year return period. Rejang Lebong District had the lowest acceleration values of 0.2973, 0.3556, 0.4404, 0.5101 and 0.5840 g. This is because the area is located far from the megathrust source and the Sumatran fault.

Figure 7 shows the fault earthquake source that dominantly affects the study area, followed by the shallow and deep megathrust and background earthquake sources. This is indicated by the acceleration values in Kepahiang and Lebong districts that exceed the values from other cities on the west coast of Bengkulu Province.

The five repetition periods indicate that all cities in Bengkulu Province showed increasing acceleration. The 10,000 years return period showed that the Kepahiang and Lebong areas have an acceleration of 1.8070 and 1.8433 g, respectively. These values are significant compared to other regions, meaning the area is close to the active earthquake source.

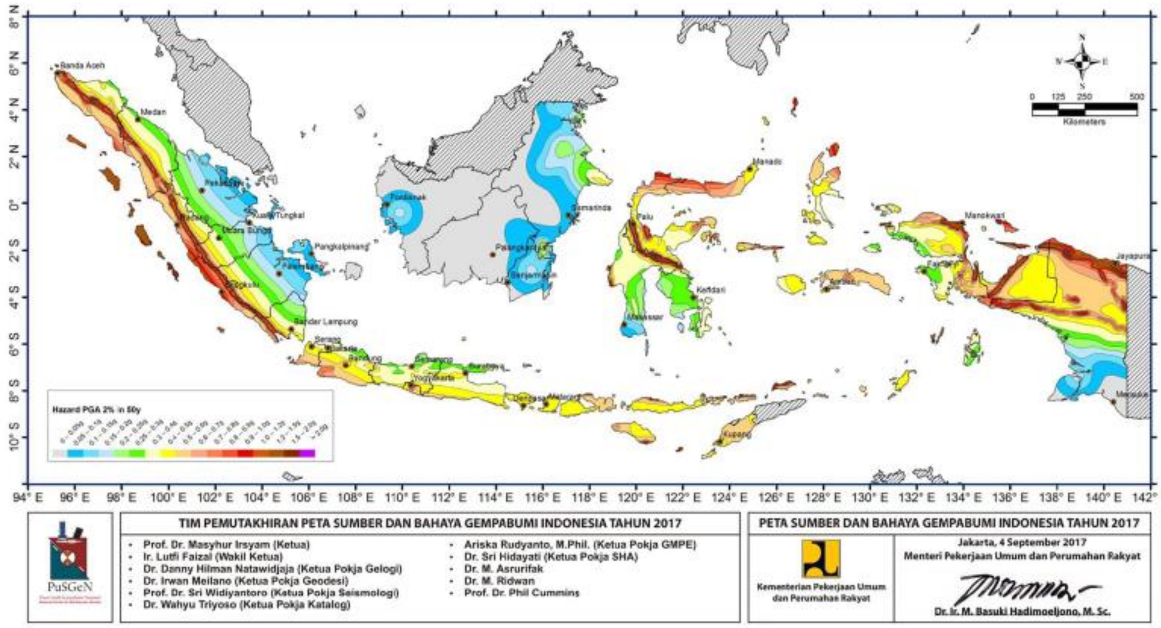

Figure 8. PGA map from PuSGeN 2017 based on the 2,500 year return periods or 2% in 50 years (Irsyam et al., 2020).

The GMPE results differed from the PGA map from PuSGeN 2017 when compared for a 2,500 years return period, as shown in Figure 8. The PuSGeN earthquake map showed that the PGA value ranges from 1.2-1.5 g, while the new GMPE indicated around 1.5-2 g (Figure 9). This implied an increment of 0.5 g in Kepahiang and Lebong, the two areas close to the Musi and Ketaun Segment fault earthquake sources.

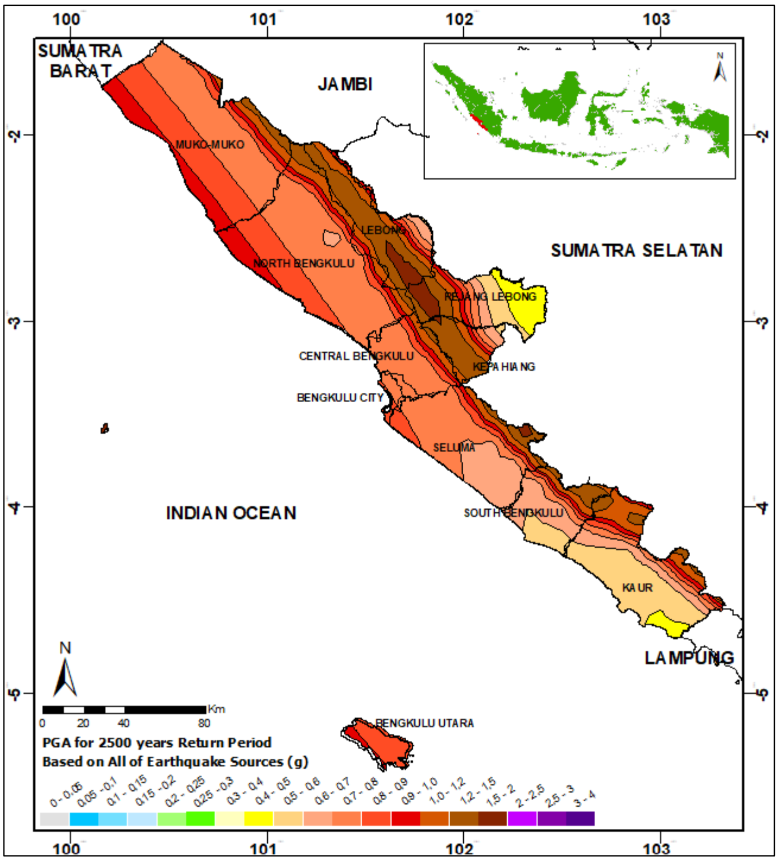

Figure 9. PGA map with 2500 years returns period or 2% in 50 years based on a study.

The results using the new GMPE differed from the PGA map from PuSGeN 2017 when compared for 500 years return period. The PuSGeN earthquake map showed PGA values ranging between 0.3-0.6 g. In contrast, the new GMPE indicated between 0.8-0.9 g, as shown in Figure 6a, implying an acceleration increment of 0.3g in the upper boundary.

The GMPE resulted in values different from the PGA map from PuSGeN 2017 when compared for 1000 years return period. Specifically, the PuSGeN earthquake map showed PGA values ranging between 0.4-1.0 g, while the new GMPE indicated around 1.2-1.5 g, as depicted in Figure 6b, implying an acceleration increment of 0.5g.

The results obtained from the new GMPE differed from the PGA map from PuSGeN 2017 when compared for 5000 years return period. The new GMPE indicated around 1.5-2 g, while the PuSGeN earthquake map showed that the PGA value ranges from 0.5-2.0 g, as depicted in Figure 6d. Moreover, there was no increment in maximum value as shown in Kepahiang and Lebong, the areas close to the Musi and Ketaun Segment fault earthquake source.

The GMPE results were different from the PGA map from PuSGeN 2017 when compared for 10000 years return period. The PuSGeN earthquake map showed that the PGA value ranged from 0.7-2.0 g, while the new GMPE indicated around 2-2.5 g, as illustrated in Figure 6e, implying an acceleration increment of 0.5 g occurred in the maximum boundary. This is because Kepahiang and Lebong districts are close to the Musi and Ketaun Segment fault earthquake source.

5 CONCLUSION

This study produced a PGA map with a 500, 1,000, 2,500, 5,000, and 10,000 years return period for Bengkulu Province based on the Earthquake Hazard Map and Source Book 2017. It also generated a Hazard Curve (HC) for ten cities with predetermined return periods. Kepahiang and Lebong districts have the highest PGA values of 1.8070g and 1.8433 g, respectively, in the five return periods. In contrast, Rejang Lebong District has the lowest PGA value of between 0.297 and 0.584 in the five return periods. This is caused by the distance factor from the earthquake sources such as faults, megathrust, and background, respectively. The Probabilistic Seismic Hazard Analysis in Bengkulu Province using the new GMPE resulted in a significant acceleration change of 0.5 g when compared to the Indonesia Earthquake Map 2017. Therefore, this hazard curve is expected to help policymakers develop infrastructure with a special design and earthquake resistance in Bengkulu.

DISCLAIMER

The author states that the research conducted is not plagiarism and does not contain elements that violate the law. The software used in the seismic analysis is the author's modification of the original USGS software. Distribution of this modified software must be authorized by the author. The use of modified software without the author's knowledge is not our responsibility.

AVAILABILITY OF DATA AND MATERIALS

The data used in this study comes from PuSGeN which has been published in the Book of Indonesian Earthquake Sources and Hazards 2017.

ACKNOWLEDGMENTS

We would like to thank Marco Pagani and Phil R Cummins for their comments and support regarding the comparison between USGS PSHA and OpenQuake. We also would like to thank Aji Febri Atmoko for fruitful discussions as well as his help and encouragement in developing the Fortran code in USGS PSHA. This research was conducted as part of the thesis and dissertation at Institut Teknologi Bandung under the LPDP foundation. We also would like to thank Research Center for Geological Disaster, National Research and Innovation Agency for supporting our activities.

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