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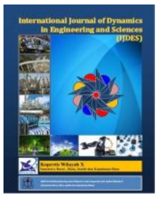

Application of The Hybrid GMPE for Seismic Hazard Analysis at Banjar City, West Java

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Abstract

Banjar is one of the important cities in West Java Province which is prone to earthquakes. Seismic hazard analysis is very important and needed to support the development and reduce earthquake risk in the city. This paper describes the use of Hybrid GMPE in Probabilistic Seismic Hazard Analysis which applied to Banjar City. The research aims to provide the probability of various ground motions during the expected major earthquakes in the future. Earthquakes data from BMKG and USGS with a radius of 300 km from the City which has been separated from aftershocks are used in this study. Earthquake source modeling is divided into megathrust, shallow crustal, and background. Hybrid GMPE is used in this analysis. Henceforth, the R-CRISIS software is used to calculate the seismic hazard. The results of the study are presented in the form of peak ground acceleration (PGA) and spectral acceleration at bedrock for a 2% probability of being exceeded in 50 years. In general, the seismic hazard at bedrock is higher in the southwest Banjar area and decreases towards the northeast. Hybrid GMPE can be an alternative in updating the seismic hazard map as a mitigation effort to reduce future earthquake risk in this region.

Keywords: hybrid GMPE, seismic hazard analysis, PGA, Banjar.

1. Introduction

Banjar City is geographically located at 108°26'-108°40' E and 07°19'-07°26' S, as a part of the West Java Province which is prone to earthquakes. Earthquake sources generators that could have an impact on the city come from local faults such as Citanduy [1], Ciremai, Tampomas, and Cirebon Fault [2], in addition to the subduction zone in the South of Java Island [3]. Several significant earthquakes that caused damage in Banjar City have been reported, including the Tasikmalaya Earthquake, December 15 2017 Mw 6.9 [4], Kebumen Earthquake, January 25 2014 Mw 6.5, and Pangandaran Earthquake, July 17, 2006 Mw 7.7 [5-6]. For these reasons, seismic hazard analysis is important for the city to reduce the risk of future earthquakes.

Seismic hazard analysis is important in disaster mitigation efforts, especially for areas that have historical destructive earthquake events that cause losses and casualties. Seismic hazard analysis assesses the occurrence of earthquakes in an area within a specified time and intensity, generally using the Deterministic Seismic Hazard Analysis (DSHA) and Probabilistic Seismic Hazard Analysis (PSHA) approaches. DSHA calculates the ground motion level by considering the worst-case scenario for a particular earthquake source, while PSHA considers the probability of occurrence from various earthquake sources.

Each earthquake source has uncertainty in the characteristics of the source and then calculated the annual probability of exceedance of a determined ground motion.

PSHA has been widely used to estimate or predict the seismic hazard of a location in terms of the worst possible consequences. The purpose of the PSHA is to determine ground motion parameters such as peak ground acceleration (PGA) and spectral acceleration. It is generally understood that the PSHA will undergo updates over time as better input models and approaches become available. Many developments have been made to improve the implementation of PSHA through updated and expanded seismic data innovation, adoption of various concepts of earthquake source zones, increased knowledge of earthquake source characterization, progress inactive fault studies, and the use of the latest generation of Ground Motion Prediction Equation (GMPE) which is suitable for an earthquake area.

The PSHA procedure requires adequate initial data, including the GMPE model. GMPE is the key linking ground motion parameters with other variables such as earthquake magnitude, source distance to the site, and local site effect [7-9]. GMPE generally describes ground vibration amplitude as a function of magnitude, distance, and site conditions, and is generally derived from empirical data of past events [10]. For this reason, the selection of GMPE must pay attention to geological, seismotectonic, and local soil conditions to reduce the complexity of PSHA and its results [11].

This study aims to apply the Hybrid GMPE model in PSHA for Banjar City, West Java. The main progress discussed in this study is the use of the Hybrid GMPE model as input in the PSHA. In addition, this paper also explores how the results of the analysis in the form of PGA and spectral acceleration are compared with previous studies. The application of the Hybrid GMPE model in seismic hazard analysis is expected to be an alternative to the GMPE model for updating seismic hazard maps in the future so that it can be useful in developing several better design methods for earthquake-resistant buildings.

2. Method

Earthquakes are natural disasters that are random and cannot be predicted, both in terms of location, time, and magnitude. By using the concept of probability, earthquake events with a certain intensity and probability can be estimated [12-13]. The concept of probability in seismic hazard analysis is known as PSHA. This study adopted this concept as the main method.

The initial stage to carry out PSHA is collecting earthquake catalogs from various sources such as the Indonesia Meteorological Climatological and Geophysical Agency (BMKG) and the United States Geological Survey (USGS). The latest catalog of earthquakes from 1900 – 2020 with various types of magnitudes is uniformed into the Mw scale for homogeneity. For PSHA purposes, only the main earthquake is included because the aftershocks are non-Poissonian. For this purpose, the declustering process to separate the main earthquake from foreshock and aftershock earthquakes is carried out.

The next step is modeling and characterizing earthquake sources that have potential impacts in the research area. Earthquake source modeling, including the probability of its occurrence in the future, could be associated with considerable epistemic uncertainty. The description of earthquake sources is generally based on geoscientific knowledge that relates earthquakes to geological structures. In this study, we include three types of earthquake sources, namely megathrust (subduction interface), shallow crustal (faults), and background earthquake sources. The background earthquake sources are earthquakes that have not been properly identified from where the source came from. Figure 1 shows the earthquake source model considered in this study.

At least two sources of M7 and M8 subduction interface earthquakes, 17 shallow crustal earthquake sources (Cirebon 1, Cirebon 2, Ciremai, Tampomas, Lembang, Cimandiri, Nyalindung-Cibeber, Rajamandala, Cirebon, Brebes, Pekalongan, Tegal, Pemalang, Ajibarang, Subang, Garsela Kencana, Garsela Rakutai) and five background earthquake sources are proposed in this seismic hazard analysis. The background earthquake sources are divided into shallow background and four deep backgrounds. In this study, the characterization of earthquake sources refers to a previous study from The National Center for Earthquake Studies (PuSGen) [2]. Table 2 is the characterization of each shallow crustal earthquake source.

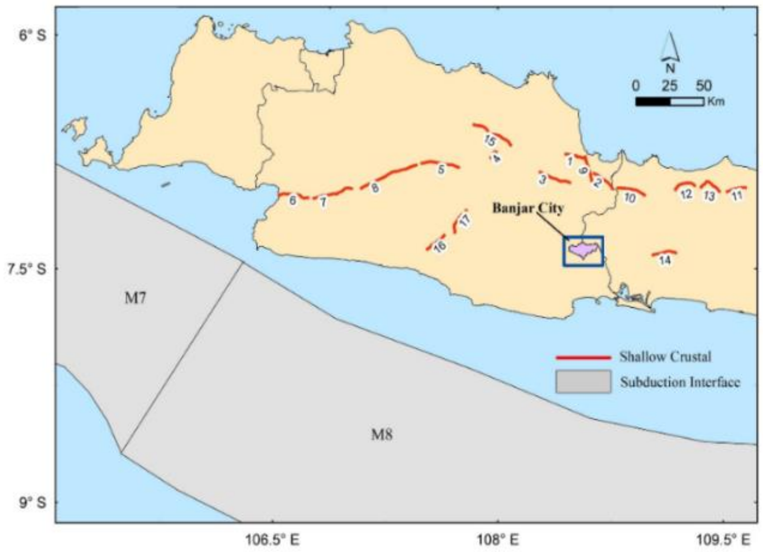

Figure 1. Simplified Traces of The Shallow Crustal Sources are Considered in The Source Modeling

Tabel 1. Shallow Crustal Earthquake Sources (Figure 1) and Their Characteristics [2]

No	Earthquake Sources	Sense Mechanism	Slip Rate (mm/yr)	Top (km)	Bottom (km)	M_{max}
1	Cirebon 1	Reverse	0.1	3	18	6.5
2	Cirebon 2	Reverse	0.1	3	18	6.5
3	Ciremai	Strike Slip	0.1	3	18	6.5
4	Tampomas	Reverse	0.1	3	18	6.5
5	Lembang	Strike Slip	2.0	3	18	6.8
6	Cimandiri	Reverse	0.55	3	18	6.7
7	Nyalindung-Cibeber	Reverse	0.4	3	18	6.5
8	Rajamandala	Strike Slip	0.1	3	18	6.6
9	Cirebon	Reverse	0.5	3	18	6.2
10	Brebes	Reverse	0.1	3	18	6.5
11	Pekalongan	Reverse	0.5	3	18	6.6
12	Tegal	Reverse	0.5	3	18	6.5
13	Pemalang	Reverse	0.5	3	18	6.3
14	Ajibarang	Strike Slip	0.1	3	18	6.5
15	Subang	Reverse	0.1	3	18	6.5
16	Garsela Kencana	Strike Slip	0.1	3	18	6.5
17	Garsela Rakutai	Normal	0.1	3	18	6.5

To estimate the ground motion parameters at each location, we apply the Hybrid GMPE model. The hybrid GMPE model is the result of a weighted combination of two or more (normal) distributions which can have different mean and standard deviation values [14-15] and formulate in equation (1).

$$P(A > a) = \sum_{i=1}^{N} W_i \left\{1 - \Phi\left[\frac{a-\mu_i}{\sigma_i}\right]\right\} \quad (1)$$

Where W_i is the weight assigned to the GMPE base i^{th}, Φ[.] is the normal distribution, μ_i and σ_i are the average values and standard deviation of the GMPE base i^{th} respectively.

In this study, the Hybrid GMPE was used by considering the basic GMPE model of each type of earthquake source. Regarding the active shallow crustal and shallow background earthquake sources, the Hybrid GMPE used the basic GMPE model of Boore-Atkinson 2008 [16], Campbell Bozorgnia 2008 [17], Chiou Youngs 2008 [18], Boore et al. 2014 [19], Campbell-Bozorgnia 2014 [20], and Chiou-Youngs 2014 [21]. Meanwhile, in terms of the subduction interface considered the basic GMPE model of Young 1997-interface [22], Atkinson Boore 2003-interface [23], Zhao 2006-interface [24], Abrahamson-interface [25]. The earthquake source of Deep Background considered the basic GMPE model of Geomatrix subduction intraslab [22], Atkinson Boore-intraslab [26], and Atkinson-Boore-intraslab Cascadia [26].

The geometry and parameters obtained above are used as input in performing PSHA with the R-CRISIS software [27], with the ability to perform PSHA using a fully probabilistic approach that allows calculating the results between outputs with different characteristics [28]. In this study, we calculate a set of hazard maps in form of PGA and spectral acceleration for 0.2 and 1 second periods as a function of the 2% probability of exceedance in 50 years or equivalent to a return period of 2475 years, following a 0.5 x 0.5 km grid.

3. Results

PSHA calculation results are presented in seismic hazard maps showing ground motion values in bedrock in terms of PGA and spectral acceleration for 0.2 and 1 second periods for a 2% probability of exceedance in 50 years or earthquake return period of 2475 years. Each acceleration period represents the vibration period of the structure for each level. The 0.2 second period is used to represent the short structure vibration period (2-floor building), while the 1 second period affects the shaking in buildings with up to 10 floors.

The results of this study indicate that the possible PGA values in the bedrock range from 0.401-0.449 g. It can be seen that the southwest part has a relatively higher PGA value and decreases towards the northeast (Figure 2). The highest PGA value is 0.449 g in Batulawang. This indicates that this area is seismically more dangerous than other areas. Furthermore, we will compare the estimated PGA value for 2% exceedance in 50 years with PGA from other studies. These results are slightly higher than the PGA results from PusGen, 2017 where the PGA results in the southwest are around 0.441 g [2].

Spectral acceleration maps provide possible seismic scenarios over a given period. They are generally used in creating a design response spectrum for structural analysis. The spectral acceleration values in Banjar City for 0.2 and 1 second periods are 0.906-0.955 g and 0.368-0.449 g, respectively. Similar to PGA, the southwest area has a relatively higher spectral acceleration value and decreases towards the northeast (Figure 3-4). The spectral acceleration values for the 0.2 periods are almost the same as the results from PusGen, 2017 where the results in the southwest are around 0.956 g. Furthermore, the spectral acceleration values for 1 second period are slightly higher than the results from PusGen, 2017 where the results in the southwest are around 0.436 g [2].

The use of Hybrid GMPE has been considered to capture the uncertainty in the estimation of the GMPE coefficient. The use of Hybrid GMPE influences PSHA results. The seismic hazard implications of PGA and spectral acceleration ranging above can cause light to moderate to heavy building damage in an earthquake event. Therefore, the structure of the building needs to be built according to the rules of earthquake resistance. The probabilistic seismic hazard map resulting from this study provides a low seismic hazard limit that is useful for engineering purposes.

This study provides an overview of the area with the highest level of hazard in bedrock located in the southwest part of Banjar City. However, the research results need to be followed up with a more detailed microzonation study because the potential for damage to building infrastructure is not only influenced by the hazard values in the bedrock but is also influenced by the local site effects.

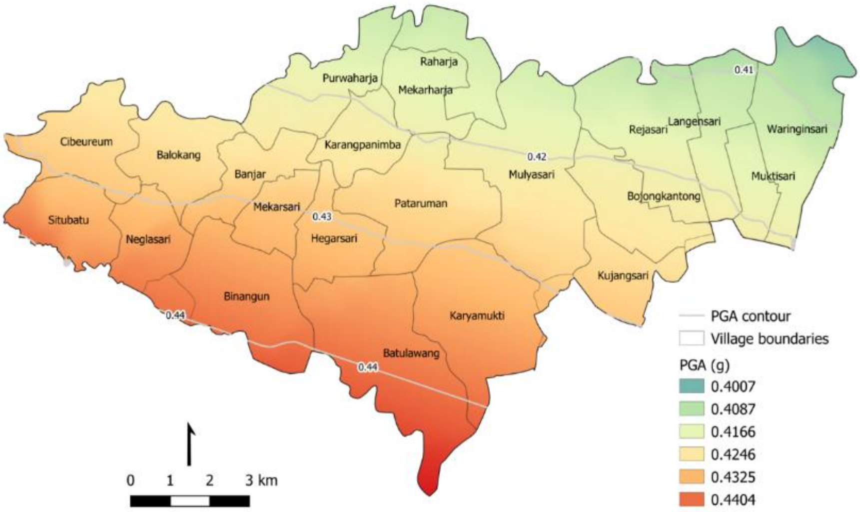

Figure 2. Peak Ground Acceleration Map at 2% Probability of Exceedance in 50 Years

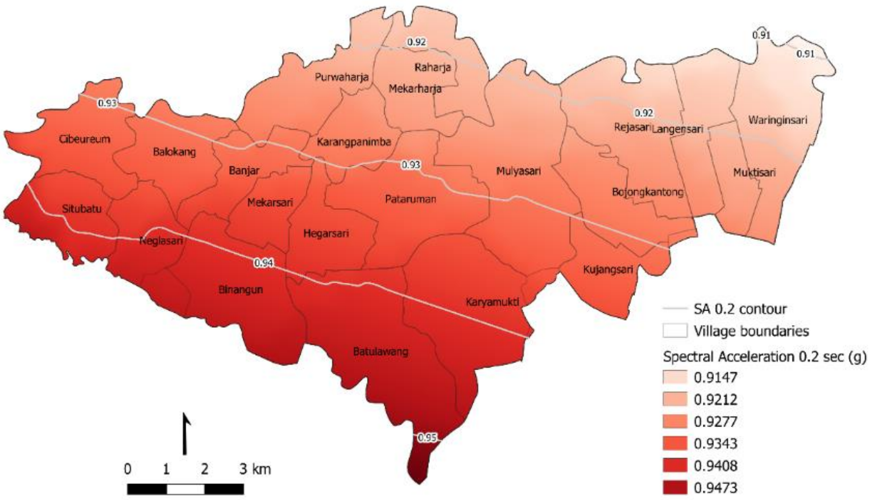

Figure 3. Spectral Acceleration 0.2 Second Map at 2% Probability of Exceedance in 50 Years

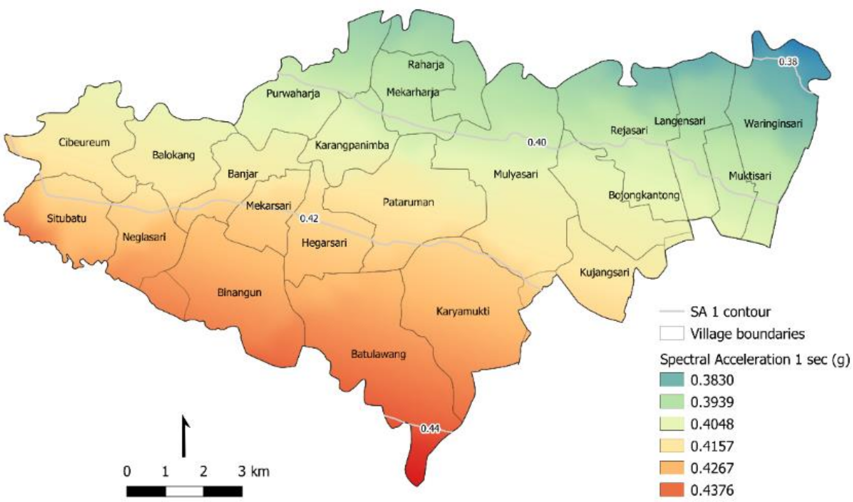

Figure 4. Spectral Acceleration 1-Second Map at 2% Probability of Exceedance in 50 Years

It is recommended that the seismic hazard maps be updated at certain periods as additional data and information become available for scientific analysis. Hybrid GMPE can be an alternative for updating seismic hazard maps as a mitigation effort to reduce the risk of future earthquakes. In general, in Indonesia, there are still more active faults that have not been properly identified and do not have detailed information to estimate the slip rate more accurately. In addition to studies related to GMPE suitable for the territory of Indonesia, further studies related to active faults are needed to improve seismic hazard maps in the future.

4. Conclusion

The use of Hybrid GMPE for seismic hazard analysis in Banjar City at bedrock level for 2% probability of exceedance in 50 years or equivalent to a return period of 2475 years showed peak ground acceleration (PGA) values 0.401-0.449 g and spectral acceleration values for 0.2 and 1 second periods are 0.906-0.955 g and 0.368-0.449 g respectively. This spectral acceleration of 0.2 second period is almost the same as the results of previous studies from PusGen 2017, but for PGA and spectral acceleration of 1 second period, the results are slightly higher. Batulawang, which is located in the southwest, has a higher level of earthquake vulnerability than other areas in Banjar City. These results need to be followed up with a microzonation study because the potential for damage to building infrastructure is also influenced by the local site effect. Hybrid GMPE can be an alternative for updating seismic hazard maps in the future.

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