Simulation of scenario seismic ground motion using GMPEs: the 5 August 2018 Lombok earthquake, West Nusa Tenggara, Indonesia

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Abstract

As the fourth most populous country in the world and located in a very active seismic zone, Indonesians encounter serious threats related to earthquakes. The 2018 Lombok earthquake sequence killed more than 500 people and damaged tens of thousands of structures, which demonstrated the impact of seismic events on this large and vulnerable community. Structural collapse was the main cause of the fatalities. In Lombok, as elsewhere in Indonesia, poverty leads to a prevalence of non-engineered and poorly constructed housing that is vulnerable to collapse during ground shaking. This study concentrates on ground motion simulation of the Mw 6.9 Lombok earthquake that occurred on 5 August 2018, for the purpose of developing a collapse fragility model. The development of a scenario ground motion model for this earthquake uses published ground motion prediction equations (GMPEs) developed for similar tectonic environments elsewhere, since there are very few ground motion recordings in the study area. This study tested four different GMPEs for active shallow crustal regions for suitability for describing ground motion in the Lombok earthquake.

Keywords: earthquake, ground motion simulation, GMPE (Ground Motion Prediction Equation)

1 Introduction

Indonesia is particularly vulnerable to earthquakes. The complex tectonic setting, which includes the convergence between Eurasian, Pacific, Indian and -Australian Plates produces high seismic activity across much of Indonesia. Lombok Island is formed because of the subduction of the Australian Plate beneath Sundaland and lies to the north of the seismogenic megathrust (Hamilton, 1979), and to the south of the seismogenic Flores back-arc thrust (Irsyam et al., 2017, Silver et al., 1983, Hamilton, 1979). The megathrust and back-arc thrusts are two major active faults that dominate the seismic activity in the region (see Figure 1).

Lombok Island, with a population of nearly 4 million (BPS West Nusa Tenggara Province, 2020), experienced a series of earthquakes in 2018. The first earthquake occurred on 28 July with Mw 6.4. This relatively shallow (10.8 km depth) earthquake (Wang et. al., 2020) caused 15 fatalities, 162 injured and thousands of houses were damaged (Robiana et. al., 2018). A week later, on 5 August, a stronger seismic event with Mw 6.9 occurred (Wang et al., 2020).

At least 563 people perished because of collapsed buildings (Disaster Info, August 2018 edition, https://www.bnpb.go.id). Two weeks later, another moderate earthquake with Mw 6.3 occurred on 19 August 2018, followed soon after by a Mw 6.9 event on the same day.

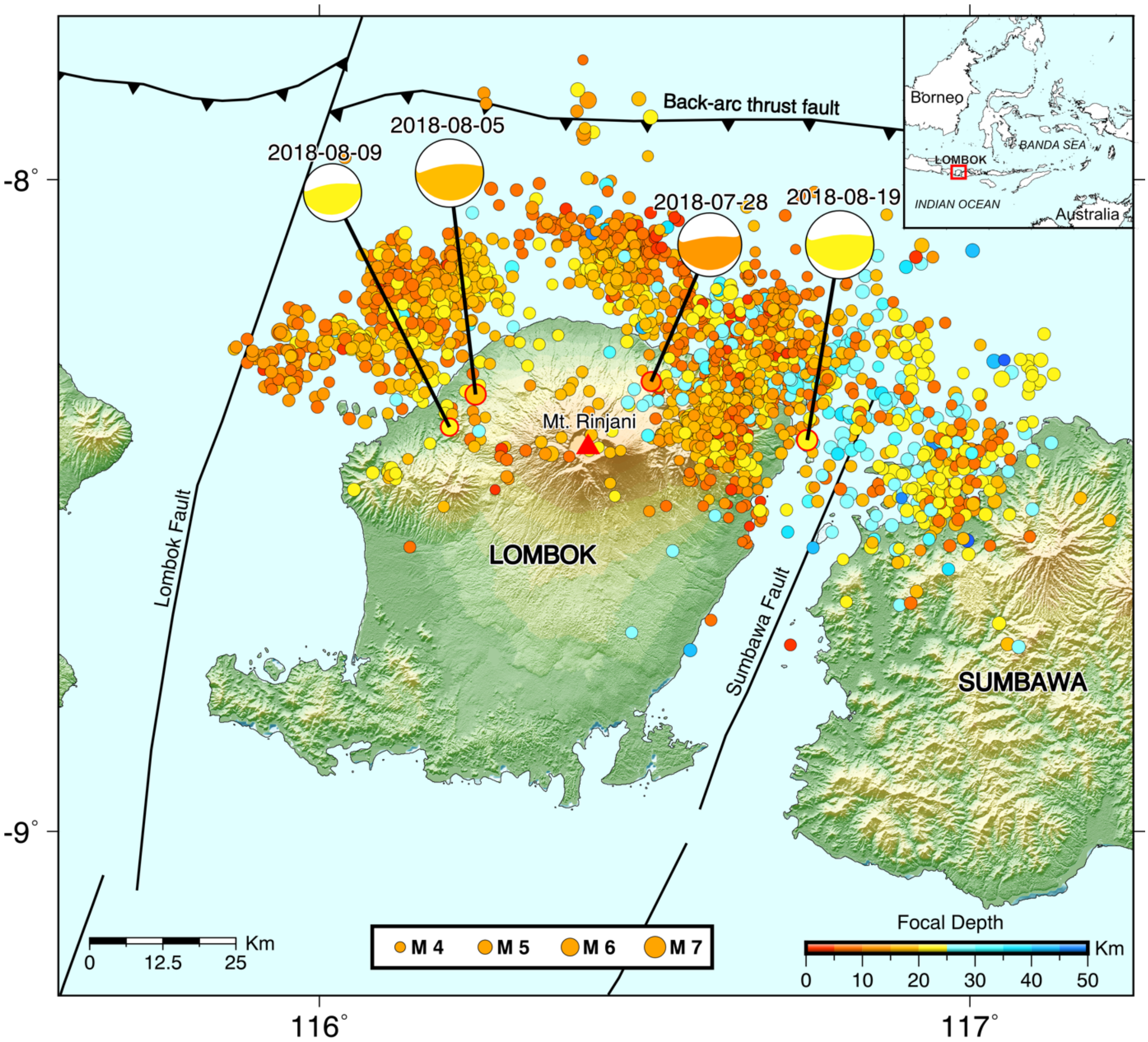

Figure 1. Lombok map showing the major tectonic boundaries of the island and the distribution of hypocentres location with magnitude ≥ 4. The subduction zone is ~400 km south of the island (not shown on the map). The location of hypocentres was acquired from Sasmi et al. (2020). Focal mechanisms of the 2018 Lombok earthquake sequences were obtained from Global CMT catalogue (www.globalcmt.org).

The four consecutive earthquakes in 2018 killed nearly 600 people and injured nearly 2,000 (Badan Nasional Penanggulangan Bencana, 2019). The Indonesian National Agency for Disaster Management recorded approximately 200,000 houses that were damaged because of the shaking. The economic losses were up to US$ 515 million (Wiwaha et. al., 2018).

This study aims to develop a scenario ground motion model for the 5 August 2018 (Mw 6.9) earthquake because this earthquake contributed the most significant casualties and building damage. The result of the simulation will be used to derive a collapse fragility model of residential building stock in Lombok Island.

2 Method

In this study, the ground motion were simulated using ground motion prediction equations (GMPEs), because there was an insufficient number of instruments to measure ground motion in the region. Developing the scenario models using this method requires three fundamental components: source parameters, GMPEs, and local site conditions.

2.1 Source Parameter

The earthquake source parameters model was adapted from Wang et al., (2020) (see Table 1). Wang et al (2020) utilised ground deformation patterns from Interferometric Synthetic Aperture Radar (InSAR) and the aftershocks of the series of earthquakes on Lombok to investigate the slip and structure of the seismogenic faults in the earthquake sequences on Lombok Island. The geodetic measurements indicated the fault planes were dipping to the south at shallow depth. The differences of the strike and dip on the faults suggested the faults are segmented, resulting in the series of earthquakes that occurred in a span of few weeks. The study also indicated the sequence of 2018 earthquakes ruptured imbrications of the Flores Back-arc thrust (Yang et al., 2020).

Table 1. Source parameters of the 5 August 2018 Lombok earthquake (Wang et al., 2020).

Mag (M_W)	Depth (km)	Lon (°)	Lat (°)	Rupture Strike (°)	Rupture Dip (°)	Rupture Rake (°)	Upper Depth (km)	Lower Depth (km)	Rupture Length (km)
6.9	15.45	-8.28	116.31	93.8	40.6	90.0	11.7	14.1	27.4

Figure 2 displays the source model developed based upon earthquake source parameters for the 5 August 2018 event.

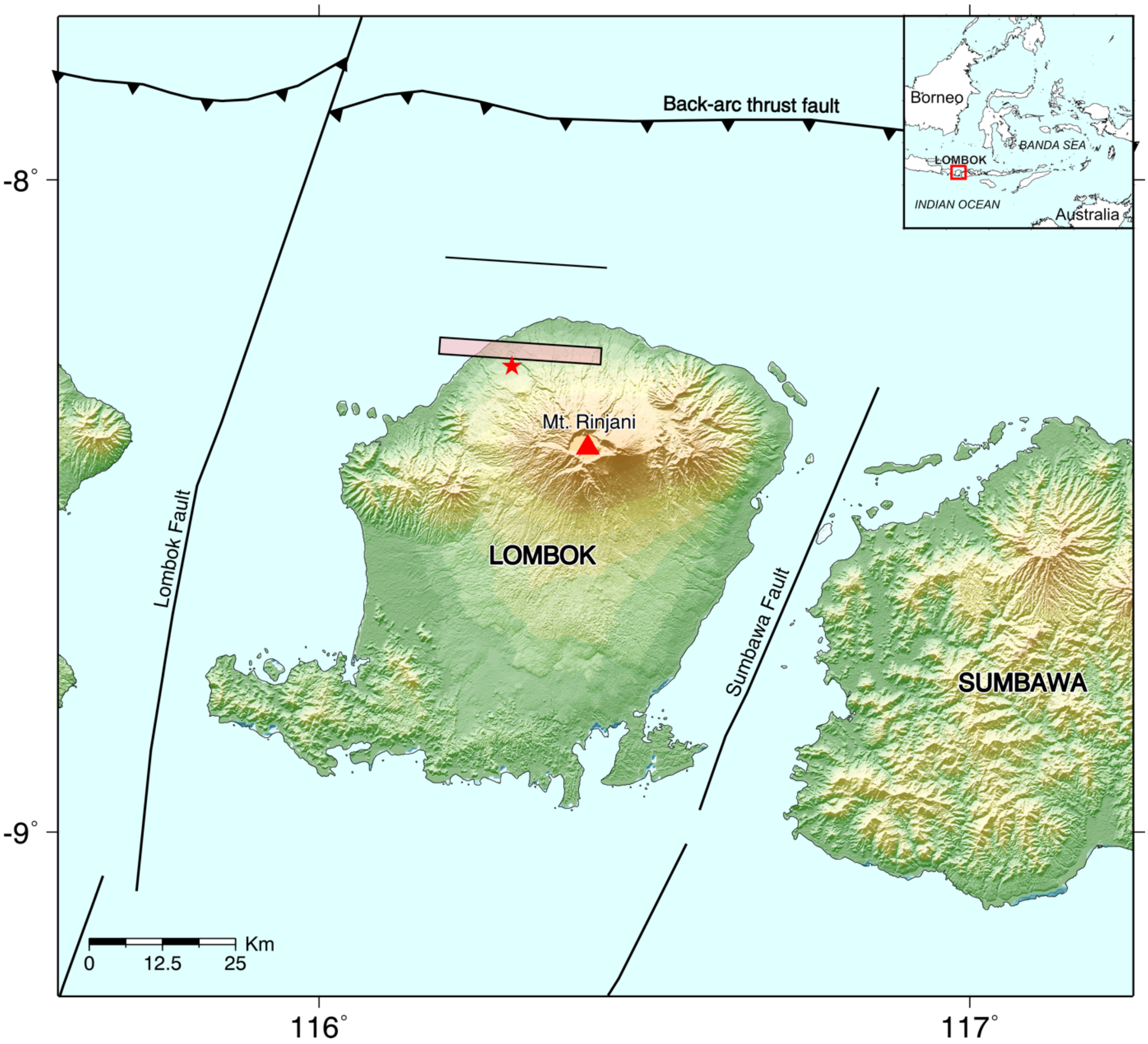

Figure 2. The rupture model of the earthquake on 5 August 2018 was developed using source parameters by Wang et al., (2020). The upper and lower seismogenic fault plane projection was depicted in a light pink rectangle. The black line located on the north of the rectangle represents upper boundary of fault projection. The red star indicates the hypocentre location, and the red triangle indicates Mt. Rinjani. The fault locations are based on Irsyam et. al. (2017).

2.2 GMPE

The second requirement to generate a scenario ground motion model is ground motion prediction equations (GMPEs) which permit us to estimate the average ground motion that varies with magnitude, source to site distance, and site effects (Elnashai and Di Sarno, 2015; Sucuoglu and Akkar, 2014; Atkinson, 2008; Douglas, 2003). The intensity measurement of a GMPE is expressed in peak ground acceleration (PGA), peak ground velocity (PGV), peak ground displacement (PGD), or spectral acceleration at different periods of vibration (SA). PGA describes the largest amplitude acceleration recorded on a local accelerometer during a seismic event and as a function of magnitude and distance between source to site (Elnashai and Di Sarno, 2015) . SA predicts accelerations associated with the forced oscillation of buildings at their natural period of vibration. Beside magnitude and source to site distance, spectral acceleration is influenced by local geology and site characteristics (Elnashai and Di Sarno, 2015). The behaviour of buildings is more closely related to spectral acceleration at their natural period than to PGA. PGA and SA are intensity measures used by structure engineering for seismically-resistant building design (Bozorgnia and Bertero, 2004).

Like many developing countries, Indonesia has not developed GMPEs specific for the country. Due to the absence of GMPEs for Indonesia, Irsyam et al. (2020) applied GMPEs developed elsewhere in their seismic hazard study of Indonesia. The selection of appropriate GMPEs is based on the similarity of the geology and tectonics of the area where the GMPE was developed to that of Indonesia. Following Irsyam et al. (2020), this study utilised GMPEs developed for active shallow crustal tectonic regions by Abrahamson et al. (2014), Boore et al. (2014), Campbell and Bozorgnia (2014), and Chiou and Youngs (2014), which are denoted AB2014, BEA2014, CB2014 and CY2014, respectively.

2.3 Local site conditions

Characteristics of local site conditions are also an essential input in the scenario ground motion model. We chose the time-average seismic shear-wave velocity to 30 meters depth (Vs30) to characterise the local site conditions. For our model simulations we used a Vs30 map that was adapted by Cipta et al. (2017) from geomorphology and geology maps in Japan and calibrated for Indonesian soil conditions. (See Figure 3).

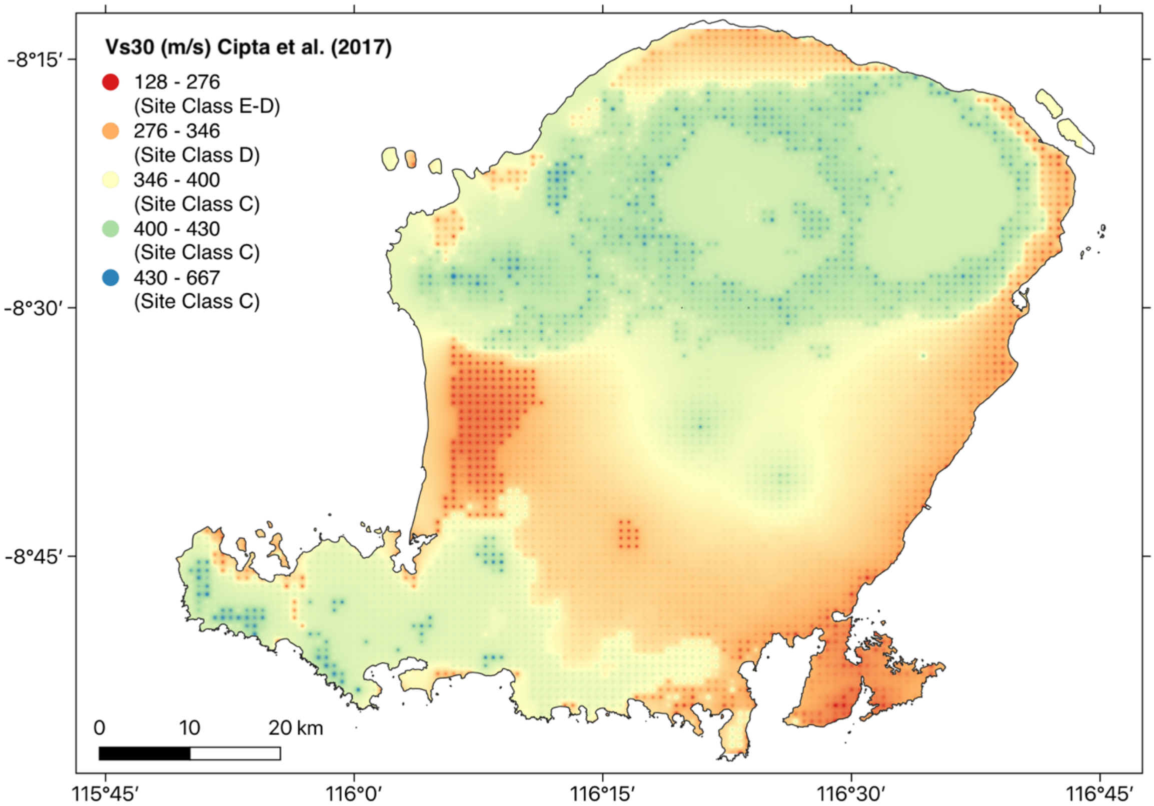

Figure 3. Site classification map of Lombok Island calculated by Cipta and Solikhin (2015) based on Geomorphology Classification Map method by Matsuoka et al. (2006). The site class referred to Standard National Indonesia (SNI 1726-2019). Site Class: C= hard soil, D= medium soil, E= soft soil.

All the input parameters used with the OpenQuake software (Pagani et al., 2014) to develop the scenario ground motion model.

3 Simulation Results

Scenario ground motion models using the selected GMPEs for the 5 August 2018 Lombok earthquake are illustrated in Figures 4 and 5. As discussed above, SA is chosen as the ground motion intensity measure to predict the structural response to a ground motion at a particular period. SA at 0.3 seconds is preferred here because the residential structures in Lombok are dominated by one-storey buildings that are most sensitive to 0.3 second or shorter period (Douglas, 2003). However, we also use PGA since is more widely used in engineering community.

Both PGA and SA can also be expressed in terms of Modified Mercalli Intensity (MMI) using the equations of Worden et al. (2012). MMI is the most well-known and globally used ground-motion intensity measure, especially in a region lacking instruments. Furthermore, the converted intensity is useful for damage prediction in the future earthquake scenario (Yaghmaei-Sabegh et al., 2011).

The simulation of the ground motion gives predicted ground acceleration values ranging from 0.02 to 0.53g. The highest PGA value (0.53g) is indicated by BEA2014 (see Figure 4). The weakest response of the ground motion is exhibited by GMPE developed by Campbell and Bozorgnia (CB2014). The variation of response intensity shown in the scenario ground motion simulations reflect the variation in each GMPE's average ground motion with distance from the source and the variant in site response as characterised by Vs30 (figure 3). The PGA values were converted to MMI using the equations of Worden et al. (2012), resulting in shaking intensity spanning from IV-VIII on the MMI scale.

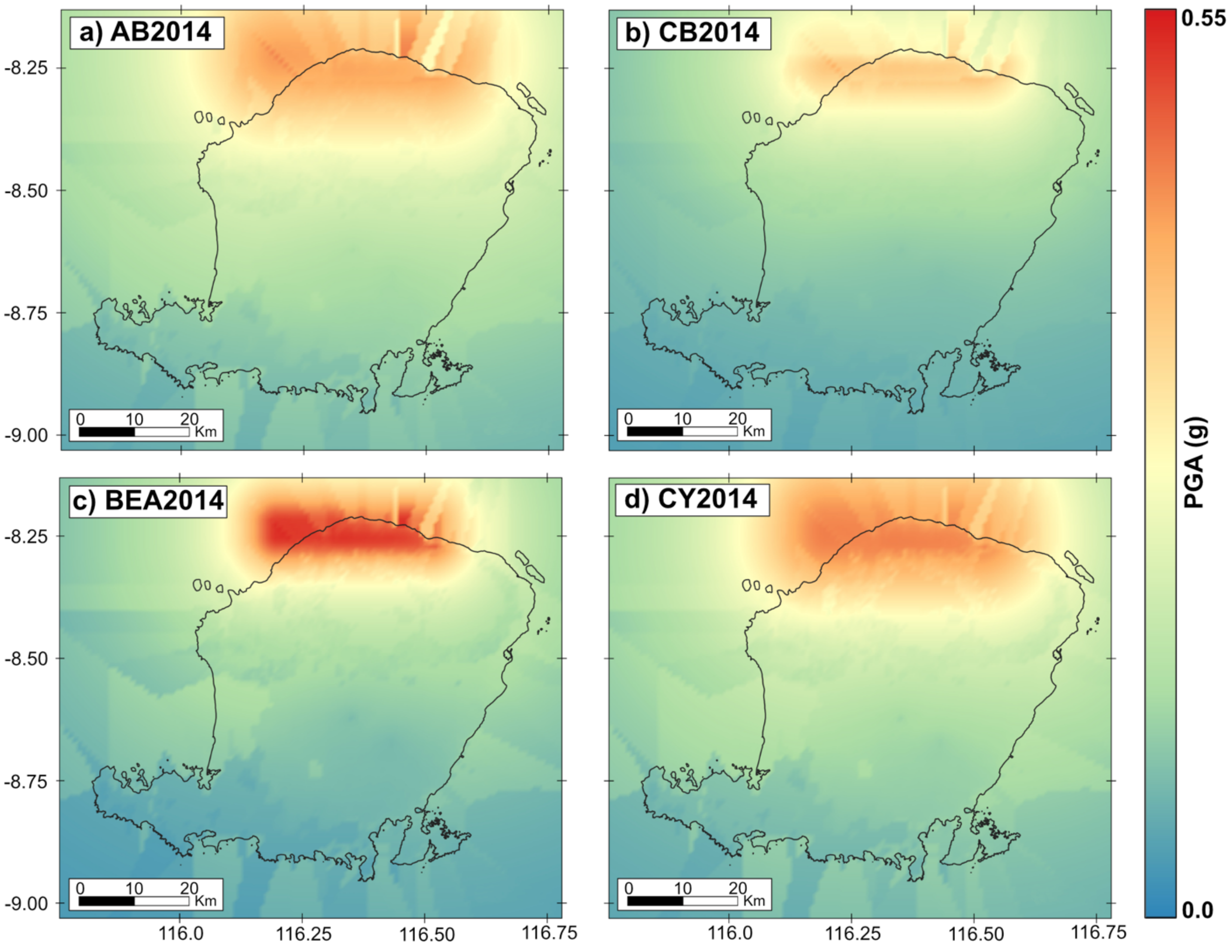

Figure 4. The simulated of ground motion models for the seismic event on 5 August 2018 show intensity variation through the island. BEA2014 (Boore et al., 2014) depicts the strongest ground response (0.53g). The jagged patterns offshore of the island were resulted from the extrapolation of onshore intensity.

The spectral acceleration (SA) intensity predictions from the four selected GMPEs are exhibited in Figure 5. The estimated SA (0.3) value ranges between 0.02-1.17 g. Using the same probabilistic ground motion parameter and Modified Mercalli Intensity (MMI) equation developed by Worden et al. (2012), the estimated SA (0.3) value is equal to III-VIII on the MMI scale.

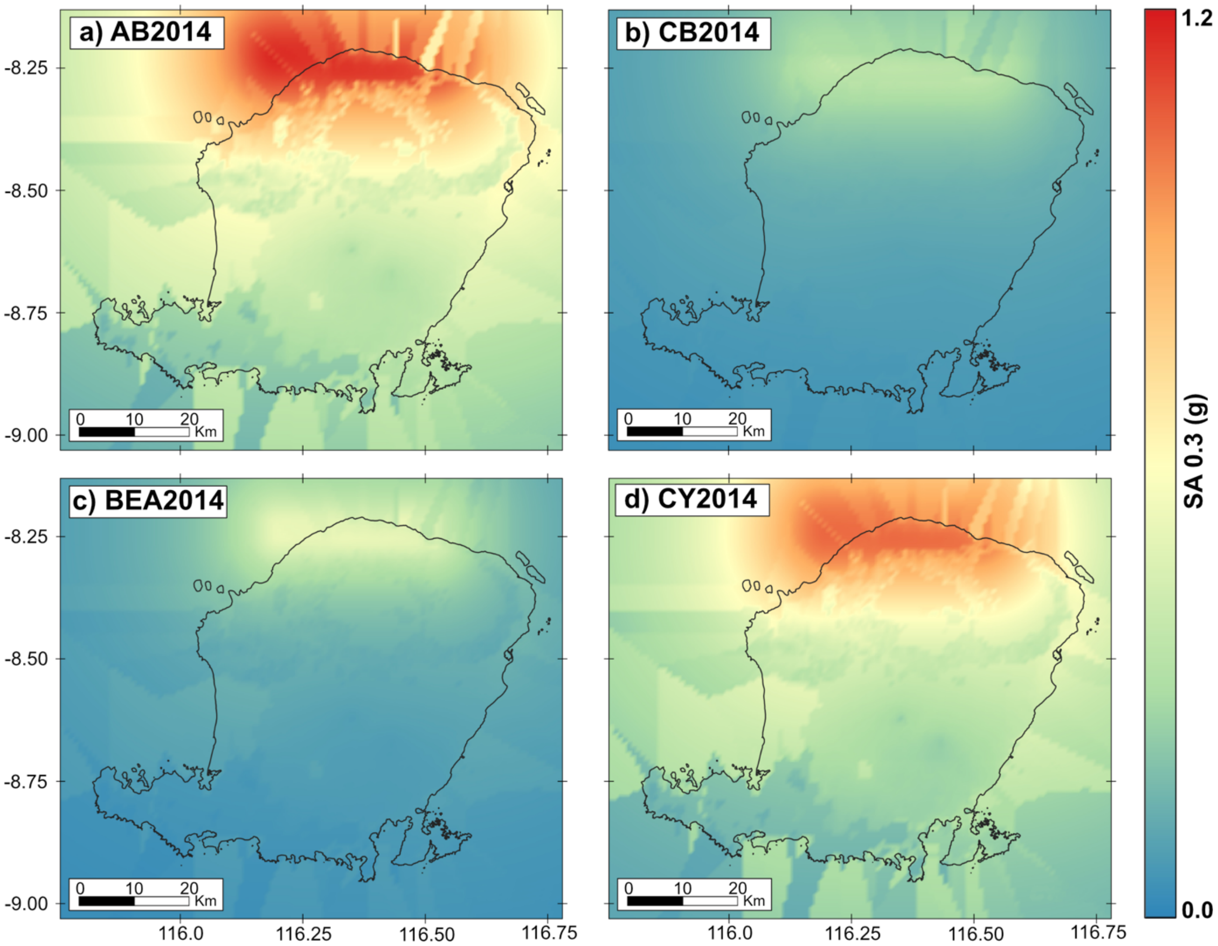

Figure 5. The comparison of scenario ground motion models showing the range of estimated response spectra at 0.3 second (SA03) in g. AB2014 (Abrahamson et al.,2014) and CY2014 (Chiou and Youngs, 2014) exhibit the strongest spectral response and correlation with the local site condition.

It is necessary to compare the PGA and SA (0.3) intensity generated from the scenario ground motion simulation with the data observed from a local instrument. The recorded data of MASE station (8.77°S, 116.28°E) from BMKG (Indonesia Meteorology, Climatology, and Geophysics Agency) IA-Networks (Pramono et al. 2020 and unpublished BMKG report) is utilised for the comparison (see Table 2).

Table 2. PGA and SA (0.3) values at MASE compared from the simulation and observation for the seismic event on 5 August 2018.

	MASE seismic station	AB2014 based model	BEA2014 based model	CB2014 based model	CY2014 based model
PGA (g)	0.038	0.192	0.131	0.133	0.179
SA 0.3 (g)	0.104	0.522	0.314	0.348	0.420

4 Conclusions

This paper computed scenario ground motion models using GMPEs for the 5 August 2018 earthquake. The purpose of the simulation is to estimate the shaking intensity hazard on the island resulting from the seismic event.

We observed the GMPEs developed by Abrahamson (AB2014) and Chiou and Youngs (CY2014) are strongly dependent on local site conditions. The comparison of the simulations and recorded ground motion reveals the intensity estimated from the empirical GMPE simulation is higher (110-134%) than the observed intensity by the seismic instrument. The overestimated intensity value generated from the simulation is not surprising given the travel path of the seismic-wave energy beneath the active volcano, Mt Rinjani, to the observation site (MASE). It should be noted that developing GMPEs suitable for a specific location is a challenging task. It requires sophisticated analysis of a large ground motion dataset that is not available for Indonesia and is beyond the scope of this study.

The ground motion intensity resulting from this study will be corresponded with the exposed building location on Lombok Island to develop a collapse fragility model of residential buildings. The model will exhibit a prediction of the probability of building damage correlate to potential seismic hazards in the future.

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