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AN UPDATE TO SEISMIC HAZARD LEVELS AND PSHA FOR LOMBOK AND SURROUNDING ISLANDS AFTER EARTHQUAKES IN 2018

Didi S. Agustawijaya[1], Rian M. Taruna[2] and Ausa R. Agustawijaya[3]

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ABSTRACT

A series of earthquakes occurred at the northern part of Lombok Island during July–September 2018 with the highest Mw7.0 5th August 2018 that caused the death of hundreds of people and ruined thousands of buildings. The earthquakes were triggered on the Flores Thrust located at the back arc zone and at only 50 km distance from the island, leading to multiple seismic hazards to Lombok and surrounding islands. The thrust could possibly be the dominant current seismic sources; however, the megathrust sources also contributed to the hazards due to the subduction between the Indo-Australia and Eurasia tectonic plates in the Nusa Tenggara region. An updated probabilistic seismic hazard analysis was, therefore, conducted on recent seismicity, detailed tectonic background, and suitable ground motion prediction equations, to determine higher seismic parameter values than the 2017 models. This means that Lombok and surrounding islands exposed to higher seismic hazards than those predicted before the earthquake events in 2018.

INTRODUCTION

A series of shallow earthquakes occurred during July-September 2018 at the northern part of Lombok Island, Indonesia, with magnitudes ranging 4–7, and the sequence lasted from July to December 2018 [1]. About 365 events occurred between 29th July and 9th August 2018, and the largest event occurred in 5th August 2018 with a magnitude of 7.0, destroying almost 800 thousand homes, and causing the death of more than 500 people [2, 3]. Most of the events occurred at the mainland or closed to the island where damages to homes, buildings, roads and bridges were inevitable, as shown in Figure 1.

Figure 1: The earthquake occurred in 5th August 2018 has ruined: A) buildings in Mataram, B) shops in Gunung Sari, C) homes in Pemenang; and D) roads and bridges in Kayangan in Lombok Island.

Lombok Island is located in the Nusa Tenggara region, which is one of the most active seismic area in Indonesia [4]. The tectonic setting of the region is part of the Sunda Arc, where the Indo-Australia ocean plate subducts beneath the Eurasia continental plate [5]; while, the Pacific plate moves to the west direction to compresses the Banda Arc then the Sunda Arc [6], as indicated in Figure 2.

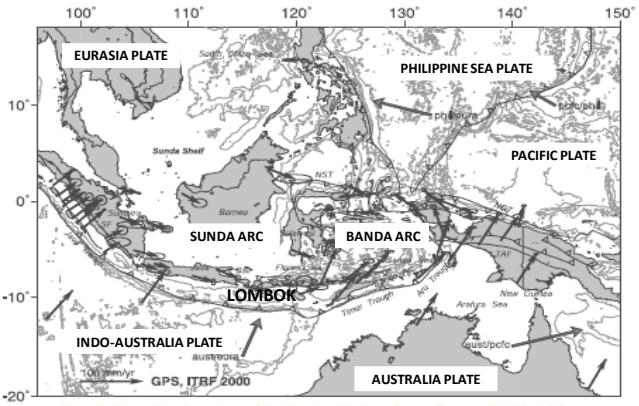


Figure 2: Tectonic pattern and geodetic ground movements of Indonesia modified from Bock et al. [6], where Lombok Island just located between the Sunda Arc and the Banda Arc.

Most of the recent Lombok earthquake events occurred at the back arc basin called the Bali Basin [4], (Figure 3). The Bali Basin is located along the northern part of Bali and Lombok Islands, connected with the Flores Basin at the northern sea of Flores Island. There is, however, an up-thrusting fault called the Flores Fault [5] or Flores Thrust (FT) [7] along these two basins. The west end of the thrust seems just to be within the back-arc zone of Lombok Island at only approximately 50 km distance from the island. Some researchers [7, 8] argued that the FT might be connected with the Kendeng Depression Zone, a major geological structure that cuts along Central and East Java

[1] *Corresponding Author, Professor, Department of Civil Engineering, University of Mataram, Mataram, Indonesia, didiagustawijaya@unram.ac.id*
[2] *Researcher, The Indonesian Agency for Meteorology, Climate and Geophysics (BMKG), Mataram, Indonesia, reemyan@gmail.com*
[3] *Student, Department of Geomatics Engineering, ITS, Surabaya, Indonesia, ausaramadhan@gmail.com*

[9]. The FT mechanisms could, however, be determined by the East Indonesia tectonic setting [10, 11].

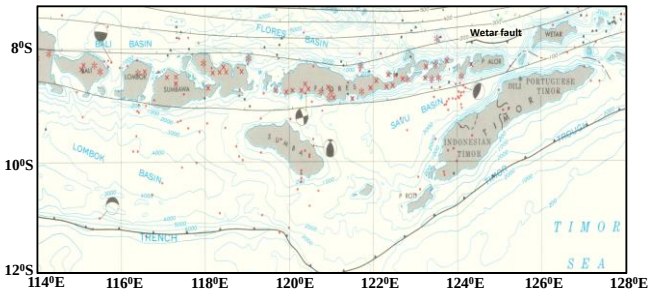


Figure 3: The bathymetry map of earthquakes in Indonesia developed in 1974 [4], showing the connection between the Bali Basin and Flores Basin in the Nusa Tenggara islands, where the Wetar Fault was first recognised at the northern part of Wetar Island, then extended to the Flores Fault located at the northern part of Flores and Lombok Islands [5, 8].

There are generally two main sources of earthquakes around Lombok Island: the south subduction-megathrust that generates deep as well as shallow earthquakes; and the north back arc thrust that conversely tends to generate shallow earthquakes [12]. Tectonic forces consequently create a lot of instability within this intensely compressed island. This may be the reason that the 2018 seismic events ruined almost one third of the island, particularly the West, North and East Lombok Districts. The past occurrences in the area were due to the back arc thrust in 1979 [13], an outer-rise earthquake in 1977 [14]; however, the influence of the reverse back arc thrust was observed to be more prominent in the seismicity of Lombok and surrounding islands than it was previously predicted [15].

An evaluation on seismic conditions of Lombok and surrounding islands should, therefore, be important to understand earthquake potential of the eastern part of the Sunda Arc system [16]. Consequently, an updated model was proposed by applying probabilistic seismic hazard analyses to review the existing seismic parameters [17] in order to have recent and up to date information about seismicity in the area.

METHODS

The earthquake catalogues for the period of 1922–2018 were derived from the United State Geological Survey (USGS) [18], the International Seismological Centre (ISC) [19], and the Indonesian Centre for Meteorology, Climate and Geophysics (BMKG) [1]. The earthquakes were recorded in various magnitude types of over 3.0 at depths of <400 km, which were then modified into moment magnitudes (Mw) according to [20, 21].

The seismicity of Lombok and surrounding islands was determined using the Gutenberg-Richter empirical relation [22]:

$$\text{Log } N_{(M)} = a - bM \quad (1)$$

where $N_{(M)}$ is the number of earthquakes with magnitude greater than or equal to M. The *a*-value is a seismic intensity parameter, which depends on the number of earthquake events. The *b*-value is a seismicity parameter determined as the linear slope on the graph of the $N_{(M)}$ number and magnitude M, or by utilizing the maximum likelihood method [23, 24]:

$$b = \frac{\log e}{M_{ave} - M_0} \quad (2)$$

M_{ave} is the average magnitude, and M_0 is the minimum magnitude.

A number of empirical attenuation relations have been suggested by many researchers, each with different characteristics, which depend on typical earthquake patterns of the location being investigated [25]. For Indonesia, six different attenuation relations have been suggested for three different earthquake sources: subduction, fault and shallow background, and deep background [21]. The Joyner-Boore relation [26] was applied for moderate to shallow sources; whereas, the Boore-Atkinson relation [27] might be applied for a shallow reverse fault, such that located at the back arc of Lombok Island [28].

Deep megathrust could generate deep earthquake events that may develop low ground accelerations. However, since various sources could generate multiple seismic events, this could create uncertainties in seismic hazard analysis. A logic tree method was, therefore, applied in probabilistic seismic hazard analyses according to [29]; as can be seen in Figure 4, all aspects of earthquakes were weighted to reduce uncertainties in seismic hazard analysis.

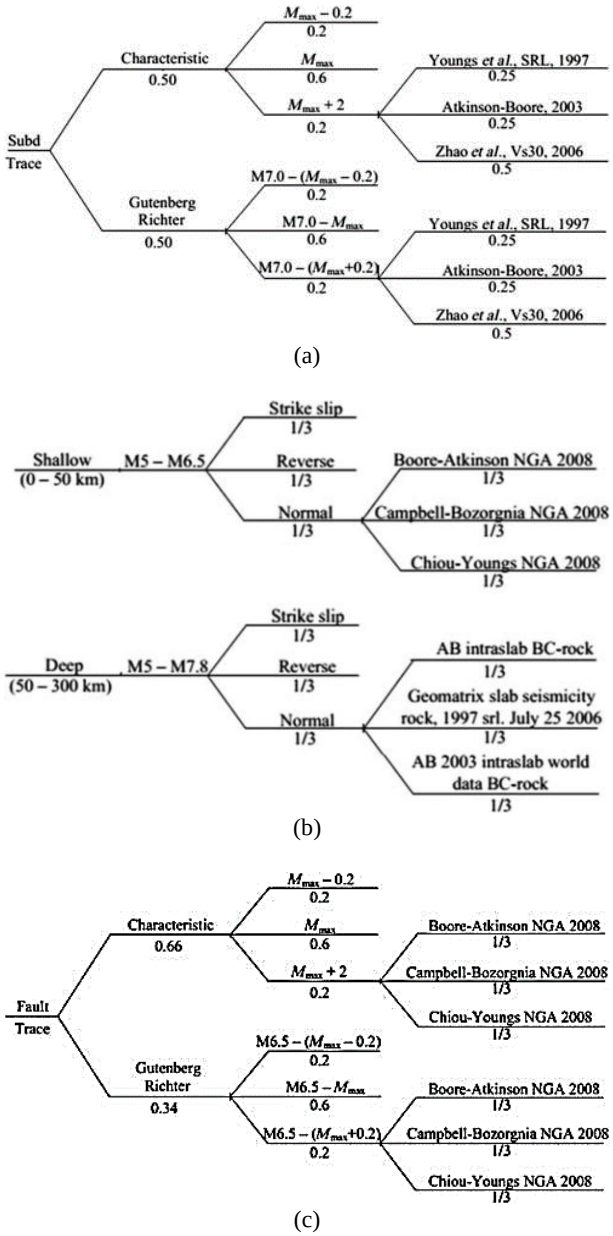


Figure 4: Logic tree of probabilistic seismic hazard analysis for general earthquake events in Indonesia: a) subduction sources; b) shallow and deep background sources; c) fault sources [29].

RESULTS AND DISCUSSION

Data Set

Earthquake data were declustered to separate the data set into independent (mainshock) and dependent (aftershock and foreshock) according to Gardner and Knopoff [30]. The declustering process was conducted using ZMAP software developed by Wiemer [31]. The process of more than 5000 data resulted in 2160 mainshocks of Mw>3.0.

According to [4, 5], these earthquake events occurred at four tectonic zones: subduction zone, fore-arc basin (Lombok Basin), magmatic-arc, and back arc basin (Bali Basin) [4], (Figure 5). The events at the back arc and fore arc basins were dominantly shallow, approximately 80% occurred at the depths of less than 100 km, and only 20% of total events occurred at the depths of 100-300 km. Few deep earthquakes occurred at the depths of >300 km, and the deepest event was at the depth of 400 km [32].

During the period of 1922-2018, about 641 mainshocks of Mw>4.5 might cause significant impacts to Lombok and surrounding islands. Interestingly, there were some events of Mw7.0 in three periodical occurrences: 1922-1927, 1978-1979, and 2009-2018; and the last two occurred at a similar location around the Bayan–Pemenang area of the North Lombok District with no intact building remaining, as shown in Figure 6.

The repetitive occurrences have been previously predicted [34], which indicated strong earthquake events of Mw6.5 might apparently occur in every forty years-period; while, shorter repetitive events of Mw6.0 might occur in every twenty years-period. A series of strong earthquakes also occurred along the particular FT in 1815, 1818 and 1820, as reported by [35].

Seismic Sources

As shown earlier in Figure 2, Lombok Island located between the Sunda Arc and Banda Arc. The island is projected to have a high seismicity index, as shown through previous estimations [34, 36], and this means that it is important to evaluate its current seismic conditions after the occurrence of earthquakes in 2018.

Three main seismic sources were applied to analyze the seismicity of Lombok and surrounding islands: subduction, background, and back arc shallow fault [21]. Background sources were particularly divided into five depth intervals [29]. Then, the Gutenberg-Richter *a*- and *b*-parameters were estimated using Equation 1. Results are depicted in Figure 7, and tabulated in Table 1 for every earthquake source.

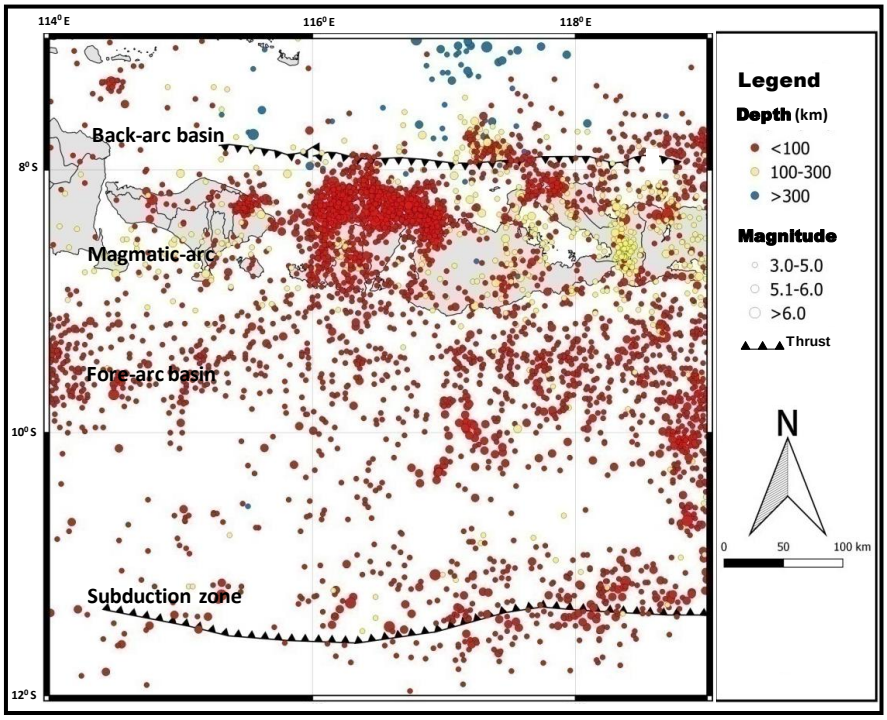


Figure 5: Seismicity map of 2160 mainshock data of Mw>3.0 during the period of 1922-2018, distributed around Lombok Island within four tectonic zones: subduction zone, fore arc basin, magmatic arc and back arc basin [4, 5].

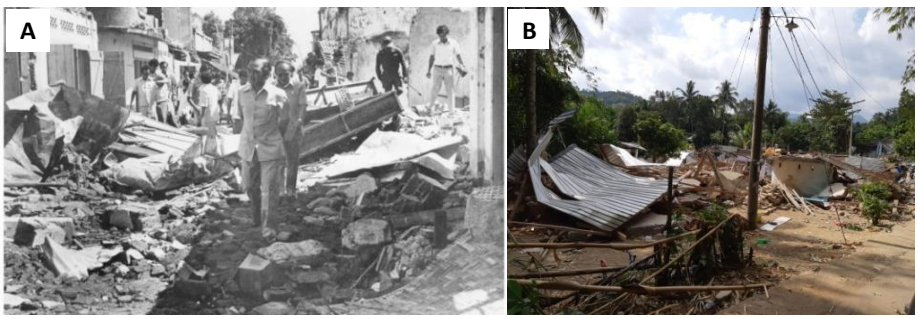
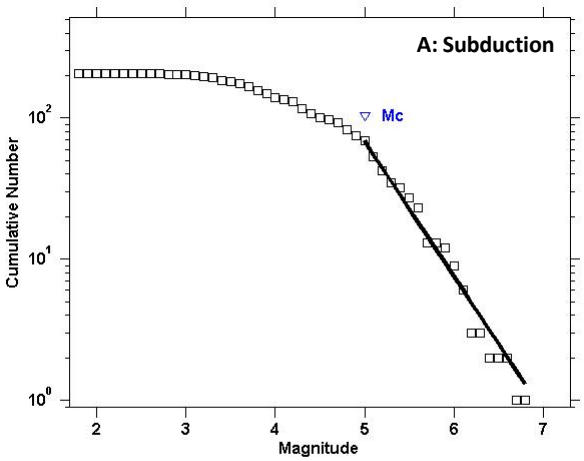
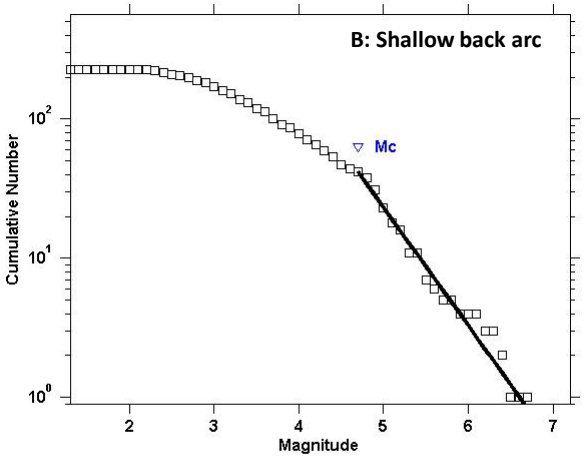


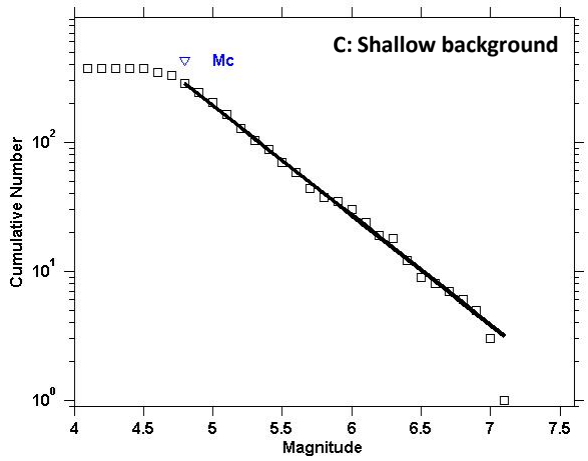
Figure 6: Ruined buildings and homes due to Lombok earthquakes at the North Lombok District: A) in 1979 [33], B) in 2018.



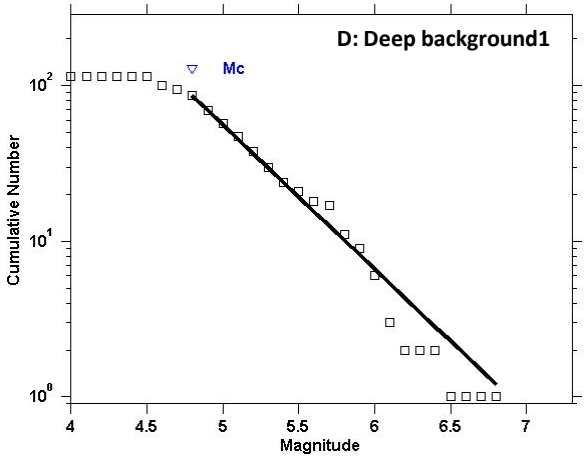
Maximum Likelihood Solution
b-value = 0.956 +/- 0.1, a value = 6.62, a value (annual) = 4.88
Magnitude of Completeness = 5



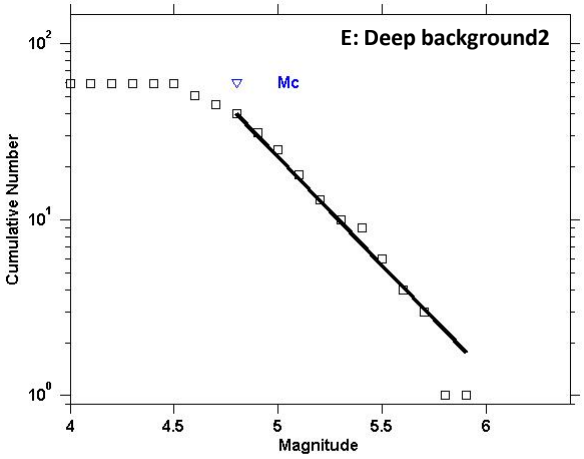
Maximum Likelihood Solution
b-value = 0.848 +/- 0.1, a value = 5.61, a value (annual) = 3.77
Magnitude of Completeness = 4.7



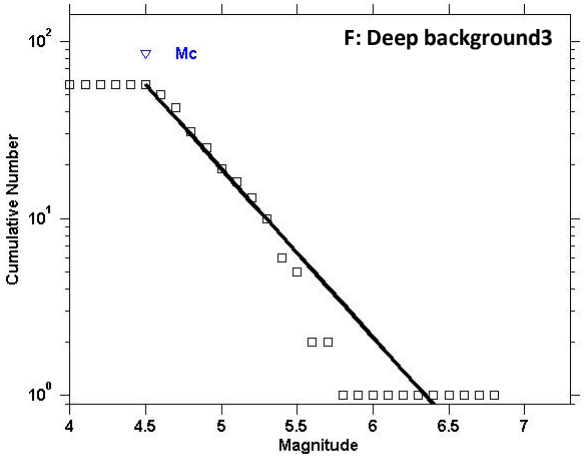
Maximum Likelihood Solution
b-value = 0.85 +/- 0.05, a value = 6.54, a value (annual) = 4.55
Magnitude of Completeness = 4.8



Maximum Likelihood Solution
b-value = 0.927 +/- 0.09, a value = 6.38, a value (annual) = 4.64
Magnitude of Completeness = 4.8



Maximum Likelihood Solution
b-value = 1.23 +/- 0.2, a value = 7.52, a value (annual) = 5.79
Magnitude of Completeness = 4.8



Maximum Likelihood Solution
b-value = 0.95 +/- 0.1, a value = 6.03, a value (annual) = 4.28
Magnitude of Completeness = 4.5

Figure 7: The Gutenberg-Richter relation for sources: A) subduction (<100 km); B) shallow back arc thrust (<50 km); C) shallow background (<50 km); D) deep background1 (50-100km); E) deep background2 (100-150 km); F) deep background3 (150-200 km).

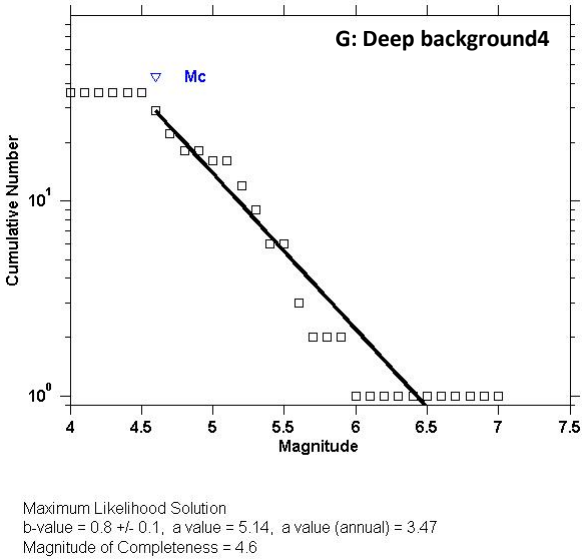


Figure 7 (Continued): The Gutenberg-Richter relation for sources: G) deep background4 (>200 km).

Table 1: The a- and b-values of the Gutenberg-Richter relation for seven sources of Lombok and surrounding islands.

Source	*a*-value	*b*-value	Mc
Subduction	6.62	-0.96	5.0
Shallow back arc thrust	5.61	-0.85	4.7
Shallow background	6.54	-0.85	4.8
Deep background1	6.38	-0.93	4.8
Deep background2	7.52	-1.23	4.8
Deep background3	6.03	-0.95	4.5
Deep background4	5.14	-0.80	4.6

Subduction (<100 km); shallow back arc thrust (<50 km); shallow background (<50 km); deep background1 (50-100 km); deep bakground2 (100-150 km); deep background3 (150-200 km); deep background4 (>200 km).

The *a*- and *b*-values were 6.62 and -0.96 for the subduction sources, 5.61 and -0.85 for the shallow back arc thrust sources, with the Mcs of 5 and 4.7, respectively. The deep background4 sources, where earthquakes occurred at the fore-arc basin and magmatic arc zones, had the lowest *a*- and *b*-values compared to other sources, which were 5.14 and -0.8 with the Mc of 4.6; whereas, the highest values were 7.52 and -1.23 with the Mc of 4.8 for the deep background2 sources.

The background sources were dominant, but they tend to produce deep seismic events, which might consequently provide low impacts to the islands, in contrast to that from the shallow back arc thrust sources. These high seismicity indexes might be influenced by many processes [23], which could be fault heterogeneity [37], and micro-fracturing [38]. In the case of Lombok Island, particularly the back arc thrust sources, the thrust is not only a complex geological feature [39], but more importantly the shallow seismic sources [35] are simply too close to the island to the extent that one third of the island was destroyed within 8 weeks during July-September 2018 [36].

Generally, an area with a low *b*-value will be potentially to have a large magnitude earthquake compared to that with a high level *b*-value [40]. This is called temporal variations in *b*-values, and such potential could impose to damaging earthquakes [41, 42]. Many studies show that the *b*-value decreased before large earthquakes, and the decrease even occurred for several years before large earthquakes occurred [40, 43]. In fact, such that low *b*-values for shallow back arc thrust source were relatively lower than that for other sources, where mostly earthquakes with Mw over 6.5 occurred in the back arc zone of Lombok Island.

Ground Motion Relation Applicable to Lombok Island

A number of empirical attenuation equations have been developed by many researchers for different tectonic characteristics [25]. Two of them, Joyner-Boore [26] and Boore-Atkinson [27], have already been recognised to be suitable for the tectonic characteristics of Indonesia [21], particularly Lombok Island [28].

According to [44], however, earthquake ground motions are influenced by source, propagation, and site effects. The Joyner-Boore equation indicates the influence of magnitude, distance, and site characterization, which was suitable for Lombok Island [28]. However, the shallow FT was observed to have a dominant influence on current seismic occurrences [12], and the closed distance of the FT to the island seemed to play a crucial role in the ground motion for the island; accordingly, the Boore-Atkinson relation was appropriate for these tectonic sources [21]. Meanwhile, the Youngs *et al.* equation [45] might be utilised for the deep subduction sources of the island.

Boore [46], however, suggested the use of a ground motion equation to provide reasonable predictions due to poor data, but, the equation is able predict engineering impacts on buildings. For the particular single event of Mw7.0 in 5th August 2018 occurred at the back arc, the Boore-Atkinson was then employed to calculate the PGA values for several most affected locations in Lombok Island [1, 18, 47], including Bayan, Tanjung, Pemenang and Mangsit in the North Lombok District; Jeringo and Guntur Macan in the West Lombok District; and Mataram City; also, for the least affected Lombok Airport. Results can be seen in Table 2, compared with that observed by Ardian *et al.* [48] and the USGS [18].

Table 2 shows that Bayan, the epicentre of the 5th August 2018 earthquake, had the highest PGA value of 1.49 g; while, other ruined locations, except the Lombok Airport, had PGA values over 0.5 g. The Joyner-Boore hypocenter distance (R_{JB}) seems to influence the calculated PGA, a location with a higher R_{JB} tends to have a lower PGA, as shown in Figure 8.

Table 2: PGA values for a single event of earthquake occurred in 5th August 2018 at various locations in Lombok Island. Comparison given between current and official analysis data reported by Ardian et al. [48] and the USGS [18] for the nearest recorder station calculated after the event, showing different values for each location.

Location / Station	PGA1 (g)	PGA2 (g) [48]	PGA3 (g) [18]
Bayan	1.49	1.07	-
Tanjung/STA30	0.74	0.75	0.79
Pemenang/STA33	0.63	0.57	0.63
Mangsit/STA29	0.54	0.45	0.68
Jeringo/STA32	0.58	0.40	0.33
Guntur Macan	0.58	0.40	-
Mataram/STA31	0.53	0.22	0.55
Lombok Airport/STA34	0.47	0.06	0.06

STA = recorder station, for example STA30 located at Tanjung in the North Lombok District [18].

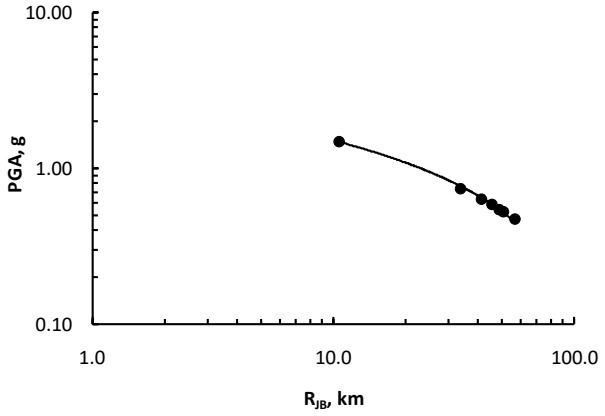


Figure 8: Plotted data between hypocenter distance (R_{JB}) and PGA value for eight locations identified in Table 2; where Bayan had an R_{JB} of 31 km, while the Lombok Airport had an R_{JB} of 57 km, with PGA values of 1.49 g and 0.47 g, respectively.

The R_{JB} values for Bayan and the Lombok Airport were 31 and 57 km, respectively; but, a PGA of 0.47 g for the airport was probably overvalued, considering the airport is located at the magmatic-arc; while, using Youngs *et al*. [45], the PGA for this particular location was 0.12 g, compared with that of the Station 34 of the USGS and BMKG was only 0.06 g. This indicates that the influence of the R_{JB} is possibly limited at long distances and deep crustal sources [49].

PGA estimations have been previously conducted before the earthquake events in 2018 [15, 17, 50]. Some previous PGA values might still be relevant; for example, for those of megathrust, but, those of back arc thrust seismic sources could be undervalued regarding the current tectonic conditions of Lombok Island. Thus, the use of seismic parameters for future civil engineering design should represent current seismic conditions, as suggested for infrastructures in Mataram City [47], and the North Lombok District [51].

PSHA for Lombok and Surrounding Islands

Probability seismic hazard analysis (PSHA) was adopted to estimate properly the devastating earthquake occurrences around Lombok Island. The purpose of the analysis is to evaluate the hazard of seismic ground motion at a site by considering all possible earthquakes within the area, estimating the associated shaking at the site, and calculating the probabilities of these occurrences [52]. The analysis should represent the most resilient means to calculate seismic load parameters, carefully chosen for seismic designs [53].

The analysis certainly involves a lot of uncertainty and variability [54], however, three important steps in the analysis: seismic source, magnitude distribution, and attenuation function, can be derived to gain the objective of the analysis. Seismic sources, magnitude distributions and the application of three ground motion prediction equations (GMPEs) for estimating the PGA values for Lombok Island have been discussed earlier.

As Lombok and surrounding islands are divided into four tectonic zones, as shown in Figure 5, the Boore-Atkinson equation [27] provided more tectonic condition effects of the shallow FT, while the Youngs *et al*. equation [45] was suitable for deep subduction sources, and the Atkinson-Boore equation [55] was suitable for deep background earthquakes. These three and other suggested GMPEs [56-58] in the logic tree method in Figure 4 were, therefore, applied in the PSHA for Lombok and surrounding islands. Although, the more updated GMPEs for shallow fault sources were applied by Irsyam *et al*. [15], the results might not be significantly different with that of the earlier version GMPEs [59], due to uncertainties in ground motion variation are incorporated into the use of logic trees [60].

The PSHA might apply two methods based on the period of observation and time. Meanwhile, it was hard to apply the time-dependent method as used by Gerstenberger *et al*. [61] in Lombok and surrounding islands due to the lack of complete data available in the early period of observation. However, both methods might be applicable for some parts of Indonesia, where data are sufficiently accurate to quantify each source for time and data production [15].

The current PSHA used the declustered data of Mw>4.5 for the event period of 1922-2018, to determine parameters for peak ground acceleration of bedrock (PGA), spectral acceleration at T = 0.2 second (Ss), and spectral acceleration at T = 1.0 second (S_1) for the applied exceedance probability of 2% in 50 years. All results are mapped in Figures 9, 10, and 11; while the PGA values (PGA1) for some cities around Nusa Tenggara and East Java are presented in Table 3, compared with the PGA2 given by Irsyam *et al*. [15].

Table 3: PGA values for various cities in the Nusa Tenggara islands and East Java after earthquakes in 2018 for the applied exceedance probability of 2% in 50 years.

Location	PGA1 (g)	PGA2 [15] (g)
Bayan (Lombok)	0.75	0.6
Mataram (Lombok)	0.65	0.5
Sumbawa Besar (Sumbawa)	0.6	0.5
Bima (Sumbawa)	0.55	0.6
Labuhan Bajo (Flores)	0.6	0.5
Waingapu (Sumba)	0.55	0.5
Maumere (Flores)	0.5	0.5
Denpasar (Bali)	0.5	0.5
Banyuwangi (East Java)	0.4	0.4

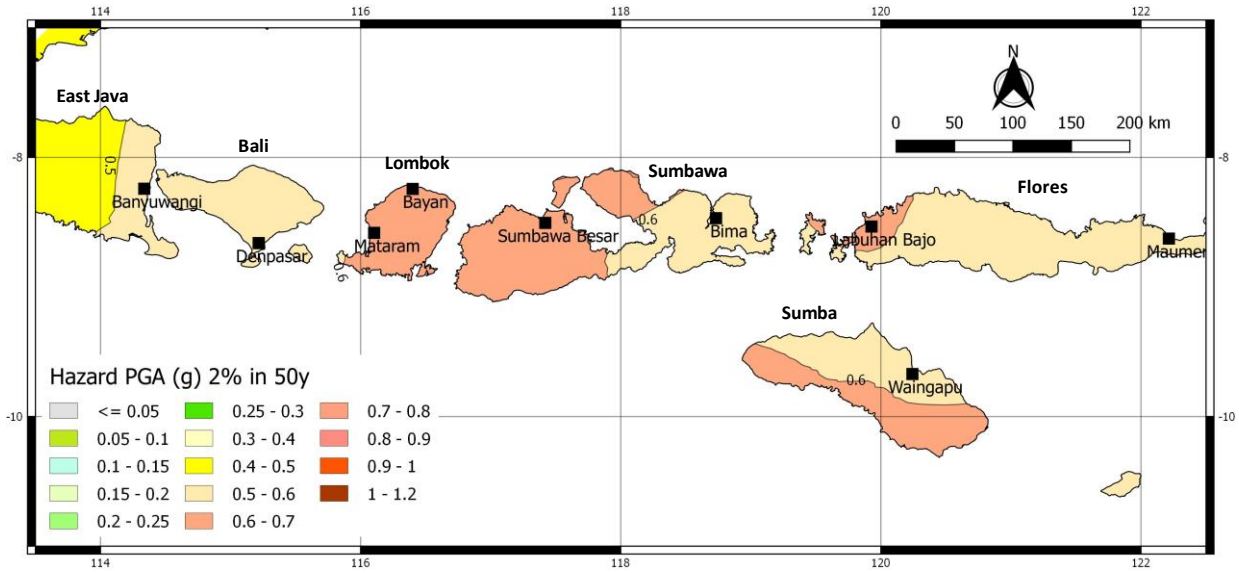


Figure 9: Map of peak ground acceleration on bedrock with an exceedance probability of 2% in 50 years for Lombok Island and surrounding islands.

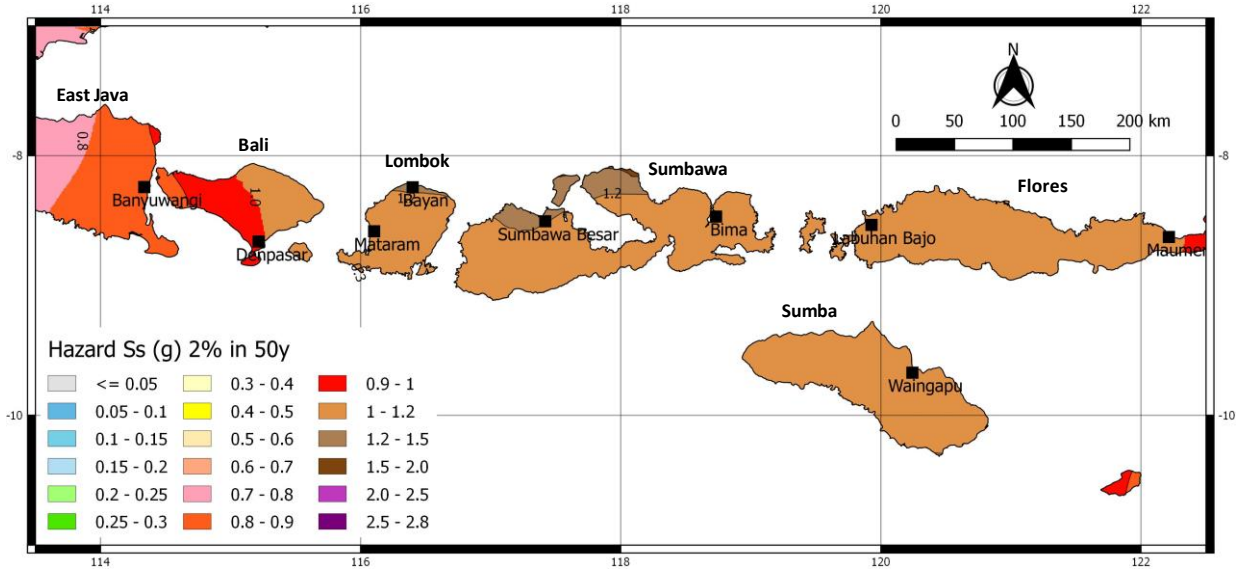


Figure 10: Map of spectral acceleration Ss (T = 0.2 s) on bedrock with an exceedance probability of 2% in 50 years for Lombok Island and surrounding islands.

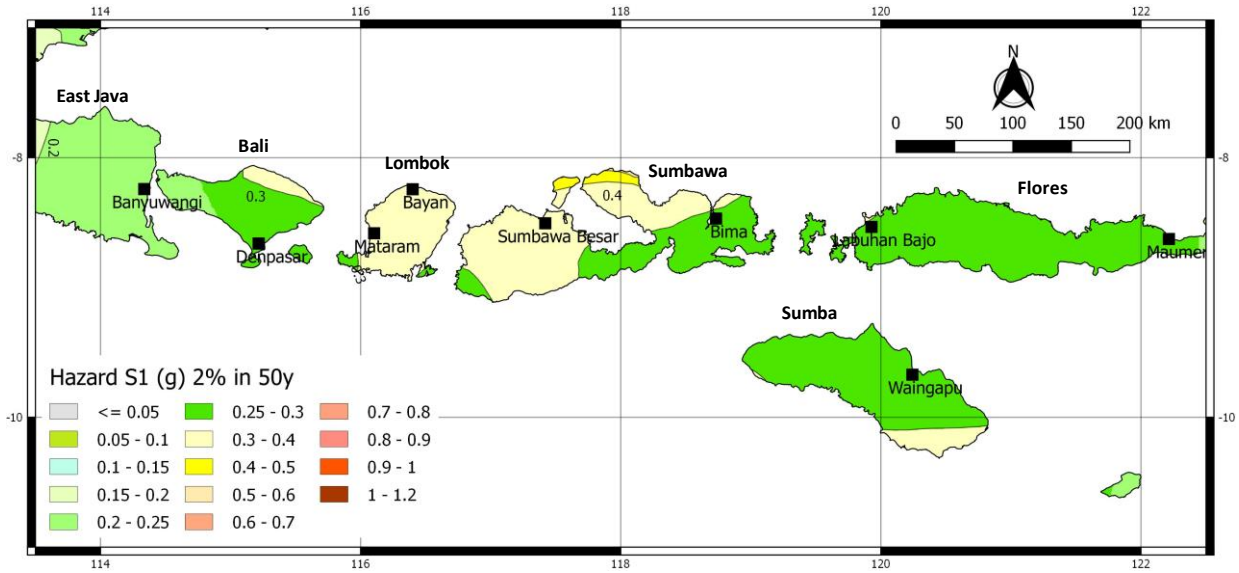


Figure 11: Map of spectral acceleration S_1 (T = 1.0 s) on bedrock with an exceedance probability of 2% in 50 years for Lombok Island and surrounding islands.

Figure 9 shows that the current PGA values of bedrock were 0.6–0.7 g for the most part of Lombok and some part of Sumbawa Islands. The highest PGA value was 0.75 g for Bayan, where was the epicentre of the 5th August 2018 event. Meanwhile, the PGA values of bedrock for other area were 0.5–0.6 g, and some parts of East Java had the values of 0.4–0.5 g.

The current PGA values of bedrock increased by approximately 6% compared to those estimated previously by Irsyam *et al*. [15] and the SNI 1726:2019 [17], as shown in Figure 12. The increase might be associated with the fact that the data used in the previous estimations were dated to 2016. In addition, the current applied maximum magnitudes were 8.0 for the shallow back arc thrust sources, and 9.0 for the subduction-megathrust sources; whereas, those of the 2017 models were 7.8 and 8.1, respectively [15, 62]. Moreover, the complexity of the back arc thrust lead to the use of the M_{max} of Mw8.5 [63] and Mw8.4 [35, 63] to reflect locking depths of 30 km of the FT [64]. A high M_{max} of approaching Mw9.0 may be hard to occur for the FT, although, a lot of uncertainty may still apply.

The differences in the PGA values also indicate the variations in seismic conditions with the back arc up-thrusting having the possibility of being more dominant in Lombok Island, as indicated in the increased maximum magnitude [59]. Furthermore, the differences in seismic sources could differentiate the PGA values between Lombok Island, Bali Island and East Java, with those of the last two locations were dominated by background sources [12, 29]. Previous research [7, 8, 39, 65] showed the complexity of the FT, and the current seismic hazard analysis discovered its significant role in the seismic conditions of Lombok and surrounding islands.

Figure 10 shows that the most Lombok Island area had the Ss values in the range of 1.0–1.2 g, while the northern part had the values higher than 1.2 g. Similar values were estimated for the northern part of Sumbawa Island, where also dominated by the back arc sources. These values were, however, higher than 0.9–1.2 g previously estimated in Figure 13 [15, 17]. One important reason could be that the quantity of big shocks and maximum magnitude increased [11].

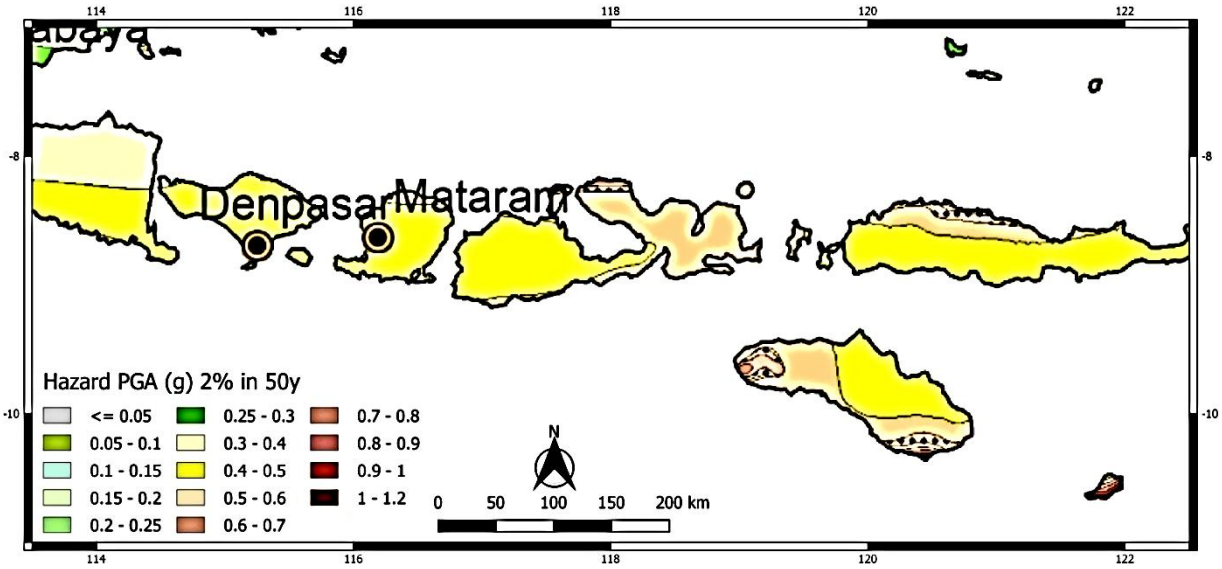


Figure 12: Map of peak ground acceleration on bedrock with an exceedance probability of 2% in 50 years for Lombok Island and surrounding islands, redrawn from Irsyam et al. [15].

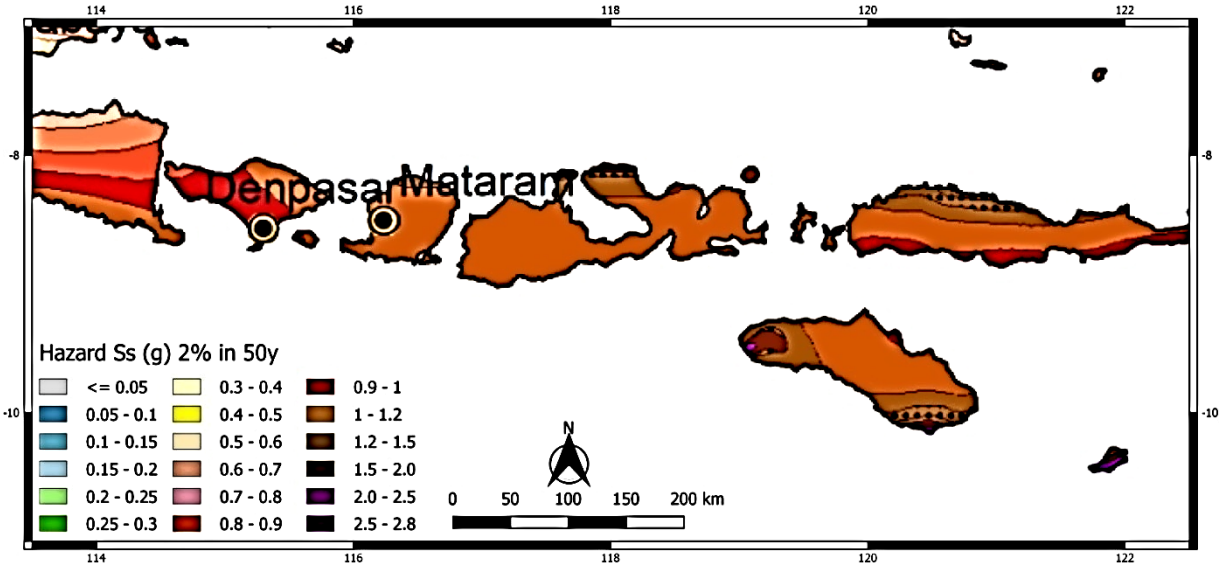


Figure 13: Map of spectral acceleration Ss (T = 0.2 s) on bedrock with an exceedance probability of 2% in 50 years for Lombok Island and surrounding islands, redrawn from Irsyam et al. [15].

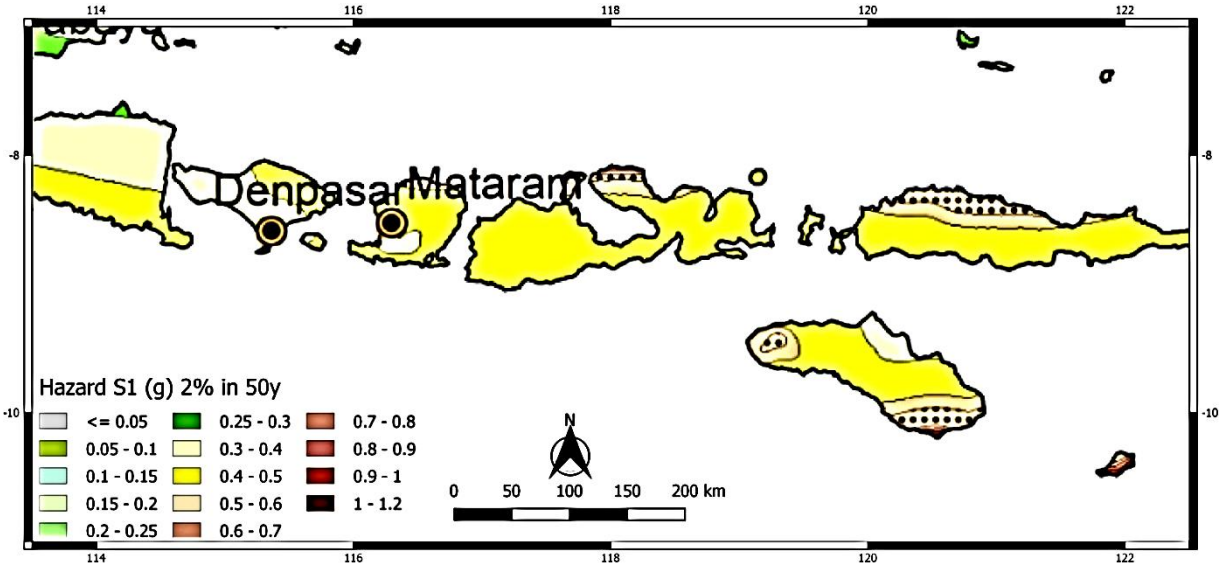


Figure 14: Map of spectral acceleration S_1 (T = 1.0 s) on bedrock with an exceedance probability of 2% in 50 years for Lombok Island and surrounding islands, redrawn from Irsyam et al. [15].

The S_1 values in Figure 11 were, however, slightly lower than the previous values [15, 17]. Particularly, the current S_1 values were 0.25–0.4 g compared to the previous 2017 models of 0.25–0.6 g for Flores and Sumba Islands. Meanwhile, the values are generally found to be in a similar range of 0.25–0.6 g for Nusa Tenggara islands, as shown in Figure 14 [15]. This possibly indicates a non-linearity estimation of the S_1 attenuation relation; and fewer effects of the changes in earthquake sources on the value for bedrock. The shock amplification of the long period of S_1 was, however, higher than that of S_0 and S_0.

Probabilistic occurrences of earthquakes around Lombok Island are high within 50 years of an exceedance probability of 2%. Earthquakes of Mw6.0 might occur within an average periodic time of 3.5 years; while that of Mw6.5 might occur within a periodic time of 10 years. These were shorter than previous estimations of 16-67 years [34]; but, still within the range of 2-12 years for Indonesia [66]. However, earthquakes with higher magnitudes of Mw6.5 may occur in a longer periodic time. When considering the last occurrence in 5th August 2018 of Mw7.0, earthquakes occurred along the FT with such a magnitude might have a periodic time of reoccurrence of 40 years, which was also shorter than previous estimations of 54-104 years [34].

Based on the last earthquake events, Lombok Island is very much vulnerable to seismic hazards. For instance, Mataram City had a high seismic intensity index of MMI VIII [67], which means that the city is susceptible to severe damage in the case of earthquakes with a PGA of 0.65 g, Ss of 1.15 g, and S_1 of 0.35 g occur within 50 years of an exceedance probability of 2% [12]. For a comparison, the City of Bima in Sumbawa Island also shows similar seismic conditions; but differs from the City of Kupang in Timor Island [68], where was dominated by subduction-megathrust sources. The PSHA parameters for Kupang were lower than those of Mataram and Bima. As consequences, probability analyses show that medium and weaker earthquakes have a bigger chance of reoccurrence in Lombok and surrounding islands, most probably within 5 years [69].

CONCLUSIONS

A series of Lombok earthquakes occurred in 2018 were triggered on the Flores Fault, located just at the back arc zone of Nusa Tenggara islands. The closeness of the complex tectonic structure to the islands, particularly Lombok, was found to play an important role in the seismicity of the region. An update to probabilistic hazard analysis, including recent seismicity, detailed tectonic background, and suitable ground motion prediction equations, showed an increase in of the seismic levels. There is an indication of higher values in PSHA parameters, such as PGA and Ss for bedrock; although, S_1 was found to be slightly lower than the estimate before the events. These increased values can be used to represent current seismic conditions, and are, therefore, applicable in future civil engineering design within the region.

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