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Updating the Background Seismicity Catalog in the Surabaya Area using USGS PSHA with a 2475-Year Return Period Study

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ABSTRACT: Seismic analysis is very important along with the development as well as the spatial and territorial layout of an area. However, unfortunately, the development of Indonesia's latest national earthquake hazard map still uses the 2017 earthquake database, not yet the latest seismic hazard catalog. This study presents an analysis using a new Probabilistic Seismic Hazard (PSHA) in the Java region, especially Surabaya, which is contains a very complex tectonic region. The Probabilistic Seismic Hazard Analysis (PSHA) includes active faults, megathrust and intraplate subduction, as well as an updated background earthquake source database and attenuation equation. The logic tree method was used to quantify the epistemic uncertainty of the source parameter components. This research calculates the bedrock Peak Ground Acceleration (PGA) with a 2475-year return period for the greater Surabaya area, which has the greatest concentrations of population and business in East Java. The analysis shows the seismic hazard is dominated by the background source in the Surabaya area. The result of this study may be useful for updating the hazard map and attracting the interest of researchers to conduct research related to seismic hazards, especially in the Surabaya area.

KEYWORDS: Probabilistic Seismic Hazard Analysis, Surabaya, Bedrock PGA, and 2475 Years Return Period.

1. INTRODUCTION

Surabaya is the capital of East Java Province and one of the largest cities in Indonesia which is dominated by two active earthquake sources due to the presence of active fault sources on land in the Java region, and due to the interaction of the Australian and Eurasian Plates (Bock et al., 2003). Historically, the Surabaya area experienced an earthquake followed by a tsunami in 1996 (Mw 7.8) and 2006 (Mw 7.7) which caused the death of nearly a thousand people in each incident (Widiyantoro et al., 2020). Therefore, it is very important to carry out continuous seismic analysis to mitigate the risks and losses due to earthquakes in this region.

Several previous research efforts have been proposed to study seismic phenomena in different regions, such as in Thailand (Mase et al., 2018a, 2020, 2021; Mase, Likitlersuang et al., 2022; Mase & Likitlersuang, 2021; Qodri et al., 2021) and Japan (Mase, Tanapalungkorn et al., 2022). As carried out by (Mase et al., 2018a), analyzed the propagation of seismic waves using the Next Generation Attenuation (NGA) analysis model on soil behavior during the Tarlay Earthquake in Northern Thailand. Further analytical studies have also been carried out by (Mase, Tanapalungkorn et al., 2022) on the liquefaction of the sand layers of the Izumio site caused by variations in ground movement during a strong earthquake in Osaka Japan, by comparing the predictions of liquefaction, which showed that in general results in this study is consistent with what other researched in seismic studies in different regions in Asia (Mase, 2017; Mase, Likitlersuang et al., 2022), and in this study, it also found that the impact of liquefaction at the Izumio site is more significant than what happened in the Tarlay Earthquake (Mase, Likitlersuang et al., 2022). The results of these various studies show how important it is to carry out further seismic analysis along with the development of spatial development in a region and also help increase awareness of the impact of earthquakes on the region. In general, seismic analysis can be carried out using two models, namely a deterministic model and a probabilistic model. The deterministic model only involves one earthquake source that is felt to have a chance of an earthquake occurring. As done by (Qodri et al., 2022) using the concept of Deterministic Seismic Hazard Analysis (DSHA) and analyzing the ground response to obtain Peak Ground Acceleration (PGA) and Spectral Acceleration (SA) for Megathrust earthquakes in Indonesia, especially the island of Java. Meanwhile, this research will focus more on a different model, namely the Probabilistic Seismic Hazard Analysis (PSHA) model (Cornell, 1968; Hans A. Merz, 1973), instead of using a deterministic model, which only focuses on one earthquake source. PSHA as a seismic hazard analysis model has a gridded seismicity model for background earthquake sources, which is used to estimate the rate of future moderate earthquake events in the fault area and random earthquakes outside the fault (Petersen et al., 2008). This model works by predicting that larger earthquake events are more likely to occur in areas around small to moderate earthquakes. As previously happened in the 2006 Yogyakarta earthquake with (Mw 6.4), which is an example of a background source that occurred in a fault area with earthquake data that had not been clearly identified (Asrurifak, 2010).

The previous research related to the PSHA model has many carried out by experts in various different of regions. As done by (Moschetti et al., 2014), developed an adaptive smoothed seismicity rate model for the Alaska region that focuses on the spatial characterization of shallow crustal earthquakes. (Syahbana et al., 2021) conducted research using a smoothed gridded seismicity model to provide recommendations for land use development in Kalimantan, Indonesia, and (Carlton et al., 2018) conducted research based on history and seismic records for background sources in offshore Bangladesh. Several other studies focusing on the Java area with various different models have also been carried out. As done by (Somantri et al., 2023) who used the NGA-West2 model and spectral matching to produce spectral acceleration during a strong earthquake triggered by a fault in the Lembang region which is known as one of the most potential faults in West Java, Indonesia, and also that conducted by (Mase et al., 2023) analyzed the ground response and potential seismic damage to structures around the Cimandiri fault, West Java, Indonesia during the Cianjur Earthquake (Mw 5.6) in 2022. The results of this research show that the Java region has the potential for earthquakes and it is very important to carry out further seismic analysis. The fact is that the island of Java has an active tectonic zone which is an active plate boundary between Australia and Southeast Asia. Moreover, in the Java subduction there any large megathrust earthquakes with a magnitude of more than (Mw 8) (Achraf Koulali et al., 2018). Such as an earthquake followed by a tsunami that occurred in the Java subduction zone on 2 June 1994 (Mw 7.8) (Abercrombie et al., 2001) and 17 July 2006 (Mw 7.7) (Ammon et al., 2006) which produced a tsunami with large local runup (> 8 m) (Bilek &

Engdahl, 2007). However, unfortunately developing the Indonesian national earthquake hazard map is still using the 2017 hazard map, which is an update of the 2010 earthquake hazard map with the addition of identified active faults (Irsyam et al., 2020). Meanwhile (National Earthquake Study Center (PUSGEN), 2022) has currently developed a deaggregation hazard map for Indonesia, which is a development of the 2017 earthquake hazard map with the new GMPE model, where the earthquake sources still refer to the 2017 earthquake catalog. Therefore, it is necessary to develop the use of the latest seismic hazard catalog, instead of only using the 2017 earthquake catalog.

This study aims to overcome the above problem by conducting a seismic hazard assessment in the Java region, especially Surabaya and its surroundings with additional earthquake background data up to 2020. This research also carries out observations of seismic sources and predictions of ground motions using a logic tree approach, which includes several branch parameters. Meanwhile, to measure the seismic hazard in this region, the USGS PSHA program is used. It is hoped that the updated seismic hazard map can represent the Peak Bedrock Acceleration (PGA) for a return period of 2475 years, which is equivalent to a 2% probability of exceedance in 50 years.

2. SEISMIC SOURCE CHARACTERIZATION

Seismic source modeling is an important initial stage in attempting a seismic hazard, which depends on knowledge of the geometry and characteristics of seismic sources that affect a particular site. The seismic source model for input to the PSHA was defined using earthquake catalogs, tectonic boundaries, and active crustal fault data. The source types in this model consisted of subduction interface sources, crustal fault sources, and background seismicity.

The shallow plate boundary where an oceanic plate is being subducted under an island arc or continent is referred to here as a subduction interface (megathrust). Each of these subduction interfaces was assigned a segmentation with maximum magnitudes inferred from the history of major earthquake occurrence, geological indicators of an along-strike segmentation, and seismogenic zone depth (National Earthquake Study Center (PUSGEN), 2017). Earthquake from those catalog with hypocenters near the subduction interface were used to determine a and b values of a Gutenberg-Richter reccurence relation for each segment as summarized in Figure 1 (Irsyam et al., 2020).

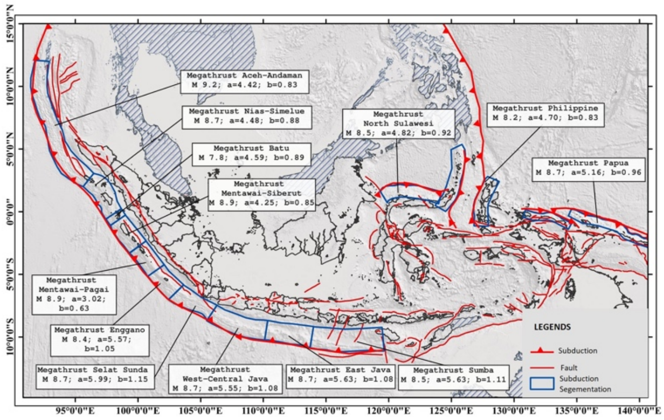

Figure 1 Subduction zone sources (megathrust) and their seismic parameters (National Earthquake Study Center (PUSGEN), 2017)

In the subduction confluence zone in the south of the island of Java, the Australian Plate moves northward, subducted by the Eurasian Plate. The development of continuous GPS installations on the island of Java was carried out to determine the plate velocity and the interplate coupling model (Hanifa et al., 2014) for Western of Java, and (A. Koulali et al., 2017) for Eastern of Java. This agrees with (Achraf Koulali et al., 2018) analysis of the offshore accretionary prism's geometry to infers that the western Java megathrust is likely to coincide with a seismogenic megathrust, whereas eastern Java is less likely to support large earthquake rupture.

Based on the condition of the relationship between tectonics and seismicity, the island of Java has several tectonic faults as a form of stress accommodation produced by subduction from the south (Figure 2). For the purpose of this analysis, the following faults were included in the Surabaya region: the Baribis Fault (A. Koulali et al., 2017; Simandjuntak & Barber, 1996), the Opak Fault (Natawidjaja, 2016), the Pati Fault (McBirney et al., 2003), and the Kendeng Fault (A. Koulali et al., 2017).

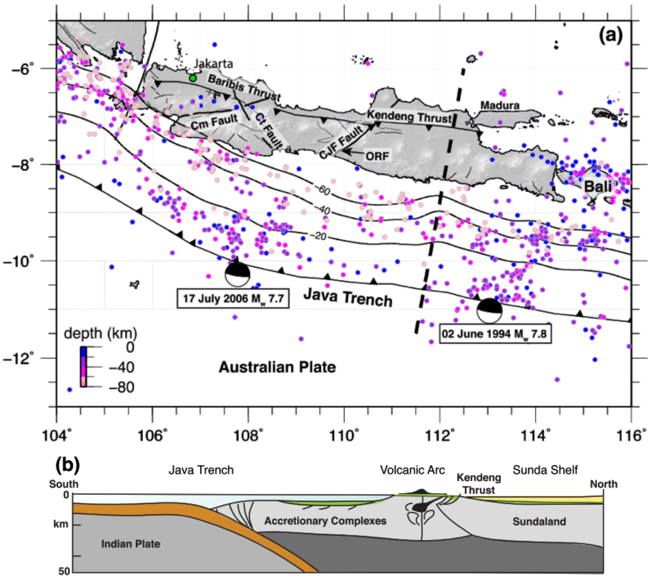

Figure 2 Active faults in Java (modified from (A. Koulali et al., 2017))

The seismotectonic lane of active faults on the Java mainland is dominated by strike-slip faults and thrust faults. Figure 2 shows that the Surabaya area is traversed by the Kendeng Fault line. The Kendeng Fault is an active fault that extends from East Java to Central Java, which then extends to the west with the Baribis Fault. The Kendeng Fault mechanism is a thrust fault and actively moves at a rate 5 mm/year (A. Koulali et al., 2017).

Background seismicity is used to account for earthquakes that cannot be ascribed to a crustal fault or subduction interface. To model background seismicity divided into six depth layers. For each of these six depth layers, we represent the background seismicity as two-dimensional grid of source points with 0.1° spacing (Frankel, 1995), with each source point is assigned a Gutenberg-Richter magnitude-frequency distribution, named MFD$_{GR}$ (Beitr, 1945).

3. SEISMIC HAZARD ANALYSIS

3.1 Probabilistic Seismic Hazard Analysis (PSHA)

The PSHA method is an earthquake hazard analysis method that takes into account and combines the uncertainty of the magnitude, location, and time of an earthquake. One software for calculating earthquake hazards uses the USGS PSHA program (Harmsen, 2007).

The USGS PSHA program is software based on the Fortran programming language developed by the US Geological Agency and used in creating the Indonesian earthquake map in 2017 which calculates earthquake hazards using the concept of the total probability method.

This program takes into account all existing earthquake source mechanisms including (1) hazSUBXnga program for megathrust earthquake sources, (2) filtrate and hazFXnga7c program for fault sources, (3) AgridMLsm and hazgridXnga2 program for background earthquake sources and hazallXL for a combination of all earthquake source mechanisms.

3.2 Seismic Sources

Seismic sources used in this study included all mechanisms (fault, megathrust, background) within 500 km the from research location. Geometry and characteristics of seismic sources derived based on (National Earthquake Study Center (PUSGEN), 2017), as shown in Figure 3.

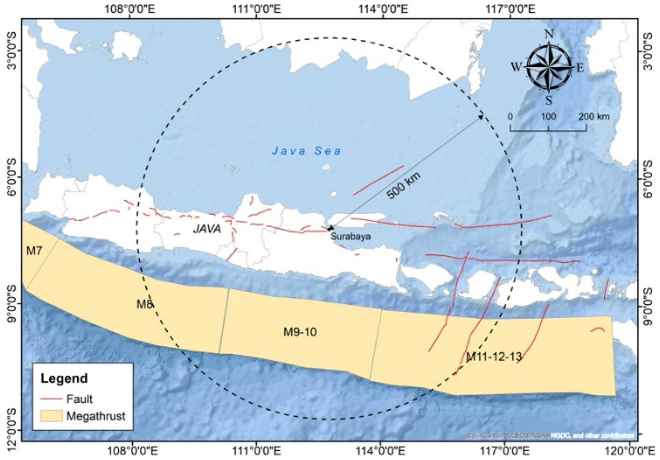

Figure 3 Map of the study area, derived based on (National Earthquake Study Center (PUSGEN), 2017)

Based on Figure 3, there are 3 subduction segments and 28 fault segments that can affect the probability of seismic hazard occurrences in Surabaya City. The data used to analyze the subduction earthquake sources such as a-b value rate, maximum magnitude (Table 1), location of subduction in latitude longitude coordinates, and limited depth of subduction zones. The a-b value were obtained from (National Earthquake Study Center (PUSGEN), 2017) catalog with hypocenters near the subduction interface from a Gutenberg-Richter recurrence relation as shown in Figure 1. The subduction zone that is shallower than 50 km is considered as the megathrust or interface zone, whereas, the earthquake occurrence deeper than the megathrust zone is classified as the Benioff zone and considered as a deep background source (Irsyam et al., 2020). The minimum magnitude is limited to more than 6.5 Mw.

Parameters of fault earthquake sources required for input of PSHA include slip rate, sense mechanism, length, width, dip, top, bottom, and maximum magnitude (Table 2). The location of each fault was determined based on information obtained from (National Earthquake Study Center (PUSGEN), 2017). For determining magnitude from fault area or surface length on different segment ruptures the relations of (Wells & Coppersmith, 1994), with the minimum of magnitude limited to more than 6.5 Mw.

Table 1 Megathrust earthquake sources

Index	Segment	a-value	b-value	M Max
M8	West – Central Java	5.55	1.08	8.7
M9 – 10	East Java	5.63	1.08	8.7
M11 – 12 – 13	Sumba	5.63	1.11	8.5

Furthermore, the model used for the background source is a gridded seismicity method, based on the seismicity rates on a spatially smoothed grid size of 0.1 x 0.1 degrees (Frankel, 1995). The gridded seismicity model approach is used to predict the possibility of larger earthquakes that may occur in locations around small to moderate earthquakes that have occurred. The magnitude of the background earthquake source is limited to the range 5.0 < Mw < 6.5 for shallow background, and 5.0 < Mw < 7.8 for deep background. This gridded seismicity model in this analysis is divided into six depth layers, i.e. shallow background source (0 – 25 km), (25 – 50 km), and deep background source (50 – 100 km), (100 – 150 km), (150 – 200 km), dan (200 – 300 km).

On other hand, value a on the fault source is calculated againts the slip rate parameters in the filtrate module, and a value on background source is calculated based on the smoothed gridded seismicity which is comprised in the agridXLsm module. For b value for all sources is 1, except for megathrust earthquake sources.

Table 2 Fault earthquake sources

ID	Segment	Slip Rate	Type	L	Dip	M Max
1	Cirebon-2	0.1	R	18	45S	6.5
2	Karangmalang	0.1	R	22	45S	6.6
3	Brebes	0.1	R	22	45S	6.6
4	Pekalongan	0.1	R	16	45S	6.5
5	Weleri	0.1	R	17	45S	6.5
6	Semarang	0.1	R	34	45S	6.9
7	Rawapening	0.1	R	18	45S	6.5
8	Demak	0.1	R	31	45S	6.8
9	Purwodadi	0.1	R	38	45S	6.9
10	Cepu	0.1	R	100	45S	7.4
11	Waru	0.05	R	64	45S	7.2
12	Surabaya	0.05	R	25	45S	6.7
13	Blumbang	0.05	R	31	45S	6.8
14	Ciremai	0.1	SS	20	90	6.6
15	Ajibarang	0.1	SS	20	90	6.6
16	Opak	0.75	SS	45	60E	7.0
17	Merapi Merbabu	0.1	SS	28	90	6.8
18	Pati Thrust	0.1	SS	69	90	7.2
19	Sumbawa North	0.5	SS	79	90	7.3
20	Sumbawa Central	0.5	SS	104	90	7.4
21	Sumbawa South 2	0.5	SS	40	90	7.0
22	Lombok North	0.5	SS	156	90	7.6
23	Lombok Central	0.5	SS	133	90	7.5
24	Lombok Sumbawa	9.9	R	310	45N	8.0
25	Bali	6.95	R	84	45N	7.3
26	Bawean	0.5	SS	156	90	7.6
27	RMKS West	1.5	SS	258	90	7.9
28	RMKS East	1.5	SS	230	90	7.8

SS = Strike Slip, R = Reverse

3.3 Attenuation

The attenuation function is generally developed based on recordings of earthquake events at a particular location. The attenuation function must consider the accuracy of predictions and data recording of earthquake events at a particular location to consider selecting the appropriate model. One of them, as verified by (Tanapalungkorn et al., 2020), uses nine different damping models to investigate the most appropriate damping model for predicting ground movements in Northern Thailand based on recorded earthquake data in the region. Of the nine different attenuation models, it was found that the NGA-West2 model was the most suitable attenuation model for predicting ground motion in Northern Thailand. The results of this research prove that it is not certain that a model that produces high accuracy in a certain area can also produce high accuracy when applied in other areas. The benefits of adjusting attenuation model analysis in certain areas can help complete data updates for recording earthquake data in certain areas, and can also provide attention to local engineers to consider the most appropriate seismic design values, especially if stronger earthquakes occur in the area. future (Mase et al., 2018b).

Earthquake hazard maps developed in a region or country must always be reviewed every certain period. The re-examination of the earthquake hazard map is triggered by changes or additions to records of earthquake events that affect an area. In the Indonesian region, the most appropriate GMPE equation is the attenuation function is generally developed based on Indonesian earthquake recording data. However, considering this is difficult to do due to the incomplete database of earthquake records in Indonesia. Therefore, the use of the attenuation function in Indonesia uses the GMPE equation based on data from other regions that have tectonic and geological conditions similar to Indonesia.

(Ariska, 2013), has carried out this comparison of 11 GMPE equations for subduction earthquake sources with accelerograph-recorded data from Java and Sumatra. The results of a study conducted by (Ariska, 2013) show that for subduction earthquake sources, the GMPE equation of (Atkinson, 2003; Youngs et al., 1997), and (Zhao, 2006) matches accelerator data from Java and Sumatra.

Another GMPE equation has also changed in the development of the 2017 Indonesian Earthquake Hazard Map for subduction earthquake sources. The new GMPE equation used is the GMPE BC Hydro equation. This GMPE equation was developed based on the results of the Senior Seismic Hazard Analysis Committee (SSHAC) level 3 study. This GMPE equation was developed from recording 10,000 earthquake data throughout the world and sourced from 300 earthquake events (N. A. Abrahamson et al., 2014; Darragh et al., 2014; Gregor, 2012). The GMPE BC Hydro equation replaces the equation of (Zhao, 2006) which is too old and not suitable for application for developing the 2017 hazard map.

To overcome the above problems, this research focuses on using the latest attenuation function adopted by (National Earthquake Study Center (PUSGEN), 2022), which is an update of the attenuation function used in developing the 2017 national earthquake map (National Earthquake Study Center (PUSGEN), 2017) with the GMPE model proposed by BC Hydro (N. Abrahamson et al., 2016); BC Rock and Global Source Subduction by (Atkinson, 2003); and (Youngs et al., 1997) which is used for subduction interface zones megathrust in the Java region. Meanwhile, for the GMPE model of active shallow crustal fault tectonic areas by (Boore et al., 2014; Campbell & Bozorgnia, 2014), and (Chiou & Youngs, 2014). For intra-slab earthquakes, GMPE is used by (N. Abrahamson et al., 2016; Zhao, 2006), and AB instraslab seismicity Worldwide Data BC-rock conditions by (Atkinson, 2003).

4. METHODS

This research began with collecting and processing background earthquake data as far as 500 km from the research location. The earthquake data used in this research was obtained from the (National Earthquake Study Center (PUSGEN), 2017) catalog and BMKG periode 2020 (BMKG, 2021) catalogues with Mw ≥ 5 to a depth of 300 km. Earthquake data for the shallow background source model was taken at a depth of 0 – 50 km where earthquakes with Mw ≥ 6.5 in the area around the fault up to 20 km from the fault line were removed. The magnitude of the background earthquake source is limited to the range 5.0 < Mw < 6.5 for shallow background, and 5.0 < Mw < 7.8 for deep background. The earthquake sources in this study are divided into 3 mechanisms, namely megathrust subduction (Table 1), fault (Table 2), and background (Figure 4).

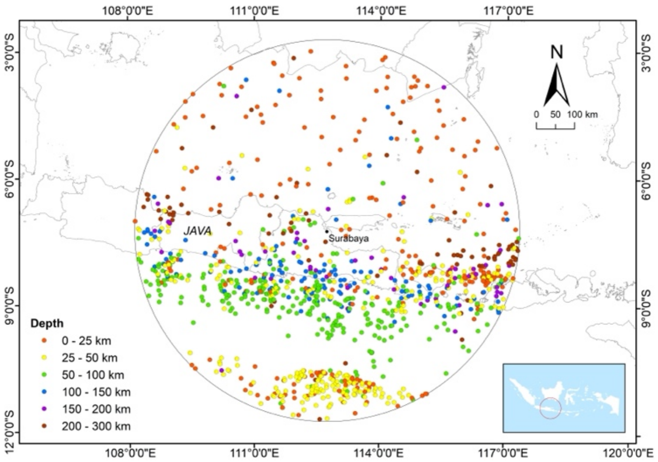

Figure 4 Background earthquake data. Derived from a combination of the (National Earthquake Study Center (PUSGEN), 2017) and catalog by (BMKG, 2021)

Based on Figure 4, the data used amounted to about 1092 earthquake data, both mainshock, foreshock, and aftershock. Then, the next step is to separate dependent earthquakes by choosing to use time and distance windows in accordance with (Gardner & Knopoff, 1974) because the PSHA analysis only uses mainshock earthquakes, this is related to the main principles of PSHA, the PSHA is utilized on a time-independent basis, thus the probability of several earthquake scenario events can be combined without changing the initial probability, according to Poisson distribution (Irsyam et al., 2020). The results obtained were 416 mainshock earthquake data after the declustering process was carried out.

The next step is to group the data to determine the level of completeness of the earthquake data using the method proposed by (Stepp, 1972). This method calculated the magnitude, and frequency based on the level of completeness of the data each earthquake duration was recorded. This procedure estimates completeness intervals by assessing the stability of the mean activity rate λ for earthquakes above a completeness magnitude with respect to a varying time interval (T) for the most recent part of the catalog. If earthquake occurrence follows a Poisson distribution and λ is constant, then its standard deviation σ varies as $1 / \sqrt{T}$. In this study, earthquake data is grouped based on magnitude, as shown in Figure 5.

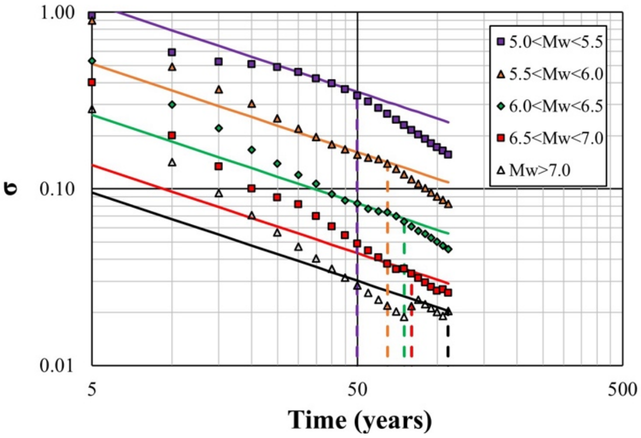

Figure 5 Level of completeness

From Figure 5, it can be seen that the data completeness results for 5.0 < Mw < 5.5 are complete since 1972, 5.5 < Mw < 6.0 are complete since 1957, 6.0 < Mw < 6.5 are complete since 1947, 6.5 < Mw < 7.0 are complete since 1942, and Mw > 7.0 complete since 1912.

The final step is weighting with a logic tree. Logic trees can be used to address the statistical uncertainties in the major elements of seismic source characterization. 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. The use of a logic tree allows the option of estimating several alternative models by determining weighting factors that describe the percentage of relative accuracy to other models. It contains several branches and terminal nodes. Every branch has a weighting factor, and it is added with other branches in the same root to construct a hazard curve in the terminal node. The total probability from all branches connected to a terminal node is unity, or equal to 1. An earthquake risk analysis is solved for model combinations and/or parameters that are related to every branch end. The outcome from every analysis is given by a relative probability weighting factor from branch combinations. The weight of the logic tree in this study refers to (National Earthquake Study Center (PUSGEN), 2022).

The relative distribution of magnitude for each seismic source was modeled using a truncated exponential mode, or a combination of truncated exponential and characteristic models with weighting. In Figure 6 shows that the logic tree 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 for subduction used in this study with a range of 0.2 Mw and GMPE based on the existing mechanism. After identifying all earthquake sources and analyzing them using each module, the next step is to add up all the outputs using the hazallXl program and the results can be read properly.

Subduction Megathrust Model

Type	Charateristic	0.5
	Gutenberg Richter	0.5
Magnitude Uncertainty	Mmax - 0.2	0.2
	Mmax	0.6
	Mmax + 0.2	0.2
GMPE	Youngs (1997)	0.33
	AB 2003	0.33
	BC - Hydro (2012)	0.33

Fault Model

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

Shallow Background Model

Type	Charateristic	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	Charateristic	0.66
	Gutenberg Richter	0.34
Magnitude Uncertainty	Strike Slip	0.33
	Reverse	0.33
	Normal	0.33
GMPE	AB Worldwide (2003)	0.33
	Zhao et al. (2006)	0.33
	Abrahamson et al. (2018)	0.33

Figure 6 Logic tree used for all sources with weighted for all earthquake sources models

5. RESULTS AND DISCUSSIONS

This research updates the PGA hazard map in Surabaya city based on probabilistic seismic hazard analysis. The maps include hazard maps due to subduction, fault, and background which represent 2% probability of exceedance in 50 years. The hazard map due to the subduction area (Figure 7) shows the largest PGA value of around 0.3 – 0.5 g in the southern part of the research location. Figure 7 shows that the PGA value will be greater is increasingly strong if it's close to the area of the subduction source, like the previous seismic hazard maps of Indonesia, which show that subduction megathrust sources dominate the hazard along the southern coasts of Java.

As well as with the fault area (Figure 8), the PGA value will be greater if it is close to the fault location. For the Surabaya area, the PGA value shows a smaller value, around 0.1 - 0.2 g. These results show that the Surabaya area although near active faults, namely the Waru and Surabaya faults, has a lower danger due to a lower slip rate of 0.05 mm/year, respectively. Different from Yogyakarta City, located near the Opak fault, which has a slip rate of 0.75 mm/year, showing a PGA magnitude of between 0.7 – 0.8 g.

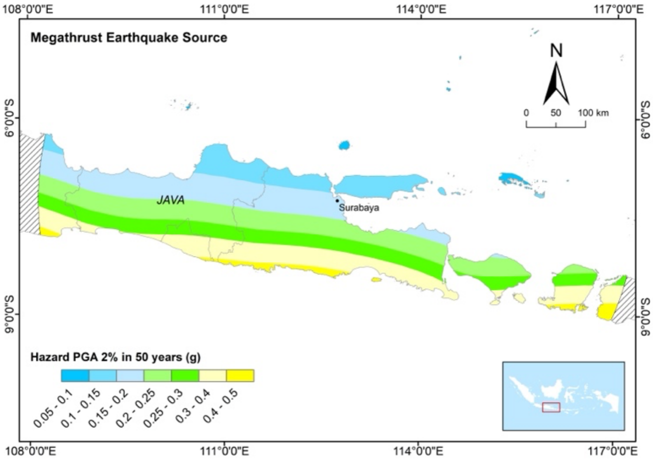

Figure 7 Hazard map based on megathrust earthquake sources

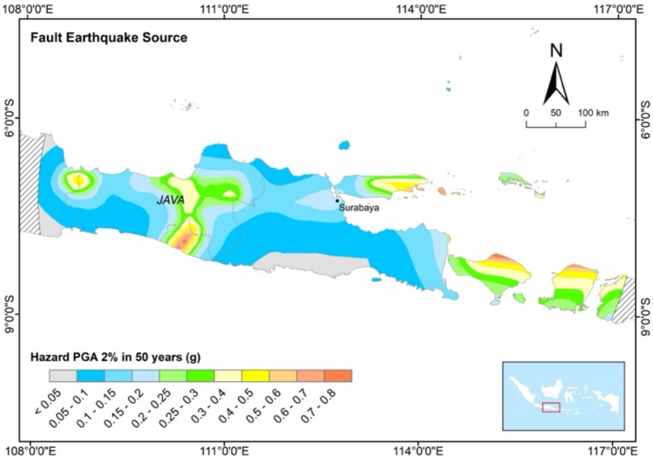

Figure 8 Hazard map based on fault earthquake sources

A different case from background sources (Figure 9). In the Surabaya area, the PGA value shows in the range of 0.25 – 0.3 g. The PGA value is greater than the result from megathrust and fault areas. This is alleged because there are fewer earthquakes occurring in the fault area than in the background earthquake source based on the updated earthquake catalogs. Finally, when combined with all earthquake sources (Figure 10), where the Surabaya area shows a PGA value in the range of 0.25 – 0.4 g.

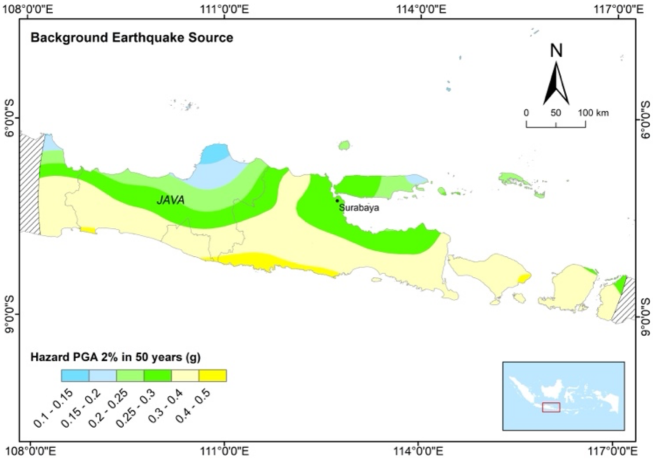

Figure 9 Hazard map based on background earthquake sources

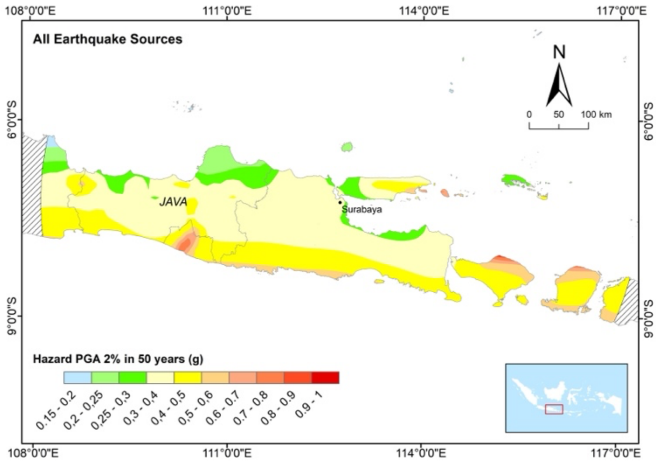

Figure 10 All earthquake sources

As a comparison with the results of this study (Figure 10) and the value of PGA produced in this study was compared with to the result of (National Earthquake Study Center (PUSGEN), 2022) as presented in Figure 11.

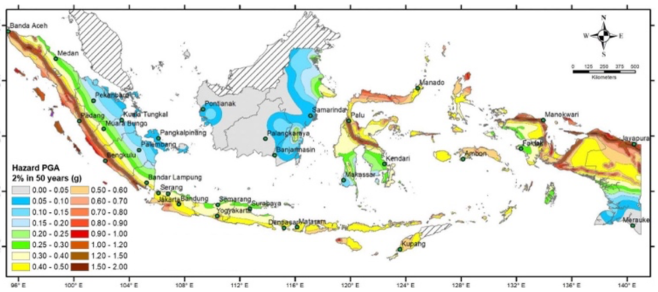

Figure 11 Bedrock Peak Ground Acceleration (PGA) with 2475-years return period (modified from (National Earthquake Study Center (PUSGEN), 2022))

From the comparison results with (National Earthquake Study Center (PUSGEN), 2022), in general the PGA values produced in Surabaya city are relatively the same, between 0.25-0.4 g. But, this research found there are differences in the gradient patterns in the northern part of Surabaya or the northern part of East Java which are allegedly due to the addition of recent earthquake events. That value of the gradient is proven that with an increase of between 0.05-0.1 g.

Furthermore, this research also shows the results of spectral acceleration design analysis in the Surabaya area involving various site class variations and compared with spectral acceleration as (SNI 1726:2019, 2019). For the Surabaya area, as shown in Figure 12a, found that the results of the spectral design acceleration were relatively the same as the results of (SNI 1726:2019, 2019). However, the results of this research in the northern part of Surabaya, as shown in Figure 12b, found that there was an increase in the design spectral acceleration value when compared with the (SNI 1726:2019, 2019) value. These results show that in this area there was an increase in the value of PGA which was allegedly by an increase in earthquake events.

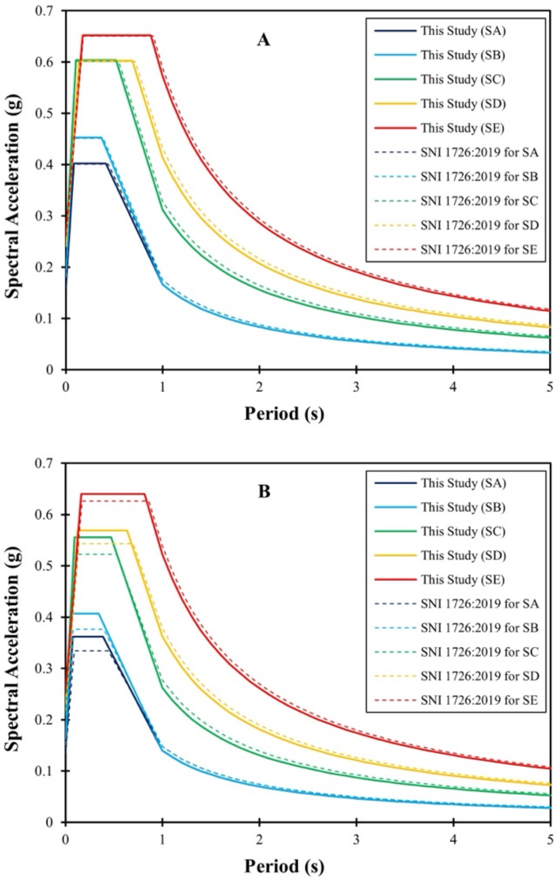

Figure 12 Spectral acceleration comparison

6. CONCLUSIONS

We developed seismic hazard maps to provide a quantitative estimation of the earthquake shaking by calculating hazard values in the Surabaya region. We describe the level of hazard by ground motion parameters given in terms of PGA for 2% probability of exceedance in 50 years, corresponding to a return period 2475 years. We noticed that seismic hazard analysis in the Surabaya area is dominated by background sources. As compared with (National Earthquake Study Center (PUSGEN), 2022), the PGA values of Surabaya City are relatively the same, around 0.25 - 0.4 g. However, in the northern part of Surabaya or the northern part of East Java increased by 0.05 - 0.1 g, which is allegedly due to the addition of a recent earthquake event. Maps presented in this study are intended for regional purposes only and may be useful for emergency response planning and development. The result of ground motion can be different between the researchers with each other depending on the database owned.

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