

RECENT DEVELOPMENT OF SEISMIC SOURCE AND HAZARD MAPS OF INDONESIA FOR EARTHQUAKE RESISTANT DESIGN

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Abstract: *The main cause of casualties from earthquakes in Indonesia arises from building and infrastructure failures due to non-compliance with seismic codes, a lack of understanding of local hazards, and additional complexity in seismic risks. Strengthening earthquake-resistant designs for buildings and infrastructure is therefore crucial. Efforts towards disaster risk reduction in Indonesia have been notable. The Ministry of Public Works and Housing (PUPR) has developed six Hazard Maps of Indonesia and consistently enhanced Building and Infrastructure Codes. The initial seismic hazard map was developed in 1966, followed by updates in 1970,*

1983, 2002, 2010, and 2017. The National Center for Earthquake Studies (PuSGeN), established and supported by the Ministry, serves as a collaborative hub for Indonesia's earthquake scientists and engineers, dedicated to refining data for national seismic sources and hazard maps and formulating earthquake resistance codes. PuSGeN has engaged in extensive partnerships with United States Geological Survey (USGS), the Australian Department of Foreign Affairs & Trade (DFAT), and the Global Earthquake Model Foundation (GEM). In 2017, PuSGeN released the most recent seismic sources and hazard maps, incorporating results from recent active fault studies, employing geological, geophysical, and geodetic observations, along with a new comprehensive earthquake catalog. This involved relocating hypocenters in a three-dimensional velocity model and modeling seismic source zones using the 2008-USGS and OpenQuake Engine software. Subsequently, impactful and destructive earthquakes occurred after the latest maps were published, providing new insights into earthquake sources. Substantial research has been conducted on active faults near major cities, including a potential active fault near the New Capital of Indonesia. Therefore, an ongoing process to update the 2017 maps is underway to better capture potential earthquake hazards. The work will consider the latest significant earthquakes, recent findings on active faults, new data, updated GMPEs, and advanced methodologies for seismic hazard mapping, all aimed at supporting earthquake-resistant design in Indonesia.

Keywords: Seismic hazard map, earthquake resistant, earthquake catalog, earthquake sources, active fault

1 Introduction

Indonesia is one of the most seismically active countries globally due to its location surrounded by three major active tectonic plates: The Eurasian, composite Indo-Australian, and Philippine plates. Given its unique position straddling two oceans and intersecting three continental plates, Indonesia has experienced some of the world's most significant and devastating earthquakes. A comprehensive seismic hazard assessment is crucial for disaster preparedness, urban planning, and infrastructure development in this region because of its tectonic setting and complex geological features. Therefore, the design and construction of buildings in Indonesia should consider this geological setting carefully. The most effective approach to mitigate earthquake-related disasters involves estimating seismic hazards and incorporating this information into seismic building codes. This ensures that structures have the necessary capacity to withstand earthquakes (Hu, 1996; Irsyam et al., 2008).

Since the establishment of the 2010 Team for Revision of Seismic Hazard Maps of Indonesia, which has evolved into PuSGeN, Indonesia has made substantial strides in earthquake mitigation efforts. PuSGeN serves as a collaboration hub for Indonesia's earthquake scientists and engineers, with a mandate to enhance data inputs for updating the national seismic source and hazard map. Additionally, it is tasked with developing national standards for earthquake-resistant buildings and infrastructure. PuSGeN has meticulously gathered findings from recent studies on active faults, drawing from geological, geophysical, and geodetic observations. They have also compiled a comprehensive earthquake catalog, which includes relocated hypocenters within a three-dimensional velocity model. This work culminated in the 2017 national seismic source and hazard map, featuring 295 earthquake sources and 16 different types of earthquake hazard maps with varying probabilities. Since then, significant earthquakes have provided valuable new insights into earthquake sources and hazard mapping. Notably, substantial research on active faults near metropolitan cities, including the elongation of Baribis-Kendeng Fault to Jakarta and the identification of a potential active fault near the New Capital of Indonesia in Kalimantan (PuSGeN, 2023).

Additionally, hazard calculation methodologies have been updated with more sophisticated modeling, software, and new Ground Motion Prediction Equations (GMPE). In light of these developments, we present the newly updated Indonesia National Seismic Sources and Hazard Map, incorporating the latest findings from significant earthquakes and active faults research.

2 Development of Seismic Hazard Maps of Indonesia

The mapping of earthquake hazard in Indonesia began with the publication of the Indonesian Concrete Codes (PBI 1966), which contained earthquake loads in all regions of Indonesia except Irian Jaya (also known as

West Papua in a recent time) that was not yet included in the territory of the Unitary State of the Republic of Indonesia. This map was an excerpt from Geophysical Note Number 2 of 1962. Subsequently, the Indonesian Loading Codes (PMI 1970) were issued, which were similar to PBI 1966, and added that part of the Irian Jaya area was included in Indonesian territory. After the 1976 Bali earthquake, the Indonesian Loading Codes (PPI 1981) were issued and continued with the publication of Earthquake Resistant Building Design Codes published in 1983 using peak ground acceleration maps. This seismic map was the result of Beca Carter's research in bilateral cooperation between Indonesia and New Zealand (Beca Carter Hollings and Ferner, 1978). This earthquake map divided Indonesia into six earthquake zones.

In 1997 the Uniform Building Code, the Earthquake Resistant Design Codes for Buildings, were published by PUPR. And so, the Indonesia National Standard or SNI 03-1726-2002 for the determination of the earthquake load design was carried out using the maximum earthquake acceleration on the bedrock (SB)) that has a 10% probability of being exceeding over 50 years, or following the earthquake return period of 475 years.

Following the occurrences of several large earthquakes which had magnitudes greater than the previously observed, such as the Aceh Earthquake of 2004, PUPR formed the 2010 Team for Revision of Seismic Hazard Maps of Indonesia to revise the 2002 earthquake map (Irsyam et al., 2010). This group involved experts in geology, seismology, geodesy, earthquake geotechnics and civil engineering from various institutions including the Bandung Institute of Technology (ITB), the Indonesian Institute of Sciences (LIPI), the Ministry of Energy and Mineral Resources (ESDM), the Ministry of Transportation, the Meteorology, Climatology and Geophysics Agency (BMKG), professional associations related to the construction industry and DFAT sponsored Australian scientists under the auspices of the National Disaster Management Agency (BNPB). The team developed the 2010 Indonesian earthquake map, based on the latest earthquake and active fault data, and used a 3-D model analysis with reference to the International Building Code 2009 (IBC 2009) that used as a reference the 2% probability of exceedance in 50 years. This was then used as a basis for determining earthquake design, followed by the SNI 1726:2012 concerning "Earthquake Resistance Design for Building and Non-Building Structures".

In 2016, PUPR took the initiative to PuSGeN for the updating of the 2010 seismic hazard maps. The results were published as the *Maps of Earthquake Source and Hazard Indonesia 2017* (PuSGeN, 2017), which has been used as the standard reference for earthquake-resistant design structures and infrastructure in Indonesia. PuSGeN consists of experts from various institutions including the PUPR, ESDM, Ministry of Research, Technology and Higher Education, Ministry of Transportation, BMKG, National Disaster Management Agency (BNPB), LIPI, Geospatial Information Agency (BIG), and practitioner/association elements (HATTI, HAGI, etc.), and is supported by international collaborations with Geoscience Australia (GA), USGS, and GEM. The 2017 seismic hazard maps consist of an active fault map of Indonesia, the PuSGeN 2016 Earthquake Catalog, a deterministic peak acceleration map in bedrock due to shallow faults and subduction earthquake sources with 84-percentile (150% Median), and Peak acceleration map on reference bedrock for return periods of 50, 100, 500, 1000, 2500, 5000 and 10000 years.

After the 2017 earthquake map was published, a series of significant earthquake disasters with unusual characteristics occurred. These include the 2018 Lombok earthquake that was characterized by a series of four large-scale shocks in rapid succession, the 2018 Central Sulawesi Earthquake that triggered tsunami waves and extreme large scale liquefaction. There were also other significant earthquakes that provided new knowledge such as Halmahera Earthquake (2019), Ambon Earthquake (2019), Mamuju Majene Earthquake (2020), Cianjur Earthquake (2022) and others. These destructive earthquake events and recent studies on active faults motivate PuSGeN to update the 2017 Indonesian Earthquake Source and Hazard Map. The work is currently being conducted, and the new Indonesian seismic hazard maps is expected to be published in 2024.

3 Earthquake Catalogue Update

To establish a reliable foundation for analysing seismic activity, recurrence studies, and probabilistic hazard assessment in Indonesia, it is essential to update the seismic catalogue. In this study, updating the Indonesia Earthquake Compilation Catalogue 2023 is done by collecting data from various agencies around the world with a spatial extent of Latitude: -15° to 12° Longitude: 90° to 145° with a time span from 1905–2022. Our compiled catalogue prioritizes sources (order indicates priority): ISC-EHB and EHB Catalog (1960-2020) (International Seismological Centre, 2023 (ISC-EHB dataset); Engdahl et al., 1998; Weston et al., 2018;

Engdahl et al., 2020), ISC-GEM Catalog (1905-2019) (International Seismological Centre 2023 (ISC-GEM Earthquake Catalogue); Storchak et al., 2013; Storchak et al., 2015; Di Giacomo et al., 2018), Relocation of BMKG Data using double difference algorithm (April 2009-2022), GCMT (1977-2021) accessed via ISC-reviewed catalog (International Seismological Centre, 2023 (On-line Bulletin; Bondár et al., 2011), and USGS Catalog (1905-2022).

To standardize the magnitude measurements in our catalogue, we follow the procedure of Scordilis et al. (2006) for mb and Ms magnitudes to estimate Mw values. A double-step conversion was also applied to convert MLv magnitudes into Mb and then into Mw. The resulting complete catalogue can be observed in Fig. 1 and Fig. 2.

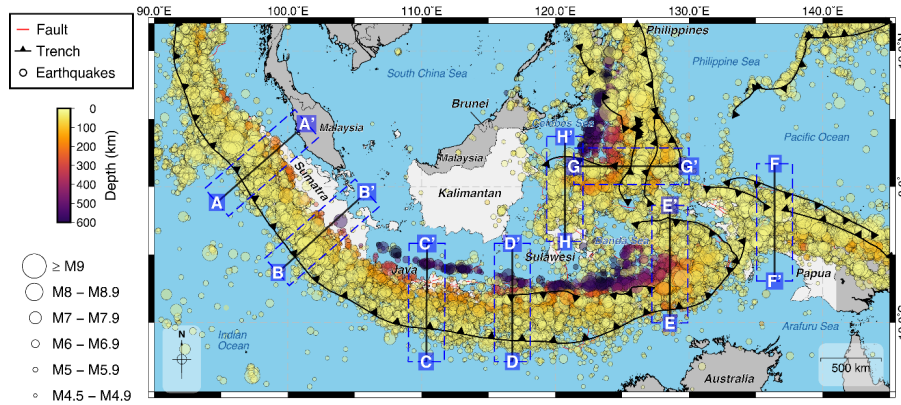


Figure 1. Distribution of epicentres around Indonesia region compiled from diverse international agencies for the 2024 PuSGeN earthquake catalogue.

4 Update of Active Faults Database

In the last few years there have been substantial updates of the active faults in Indonesia, covering new findings in Sumatera, Java, Nusa Tenggara, Sulawesi, Eastern Indonesia, as well as the new Capital of Indonesia in East Kalimantan (IKN), and megathrust segmentation from geological, geodetic, and geophysical studies.

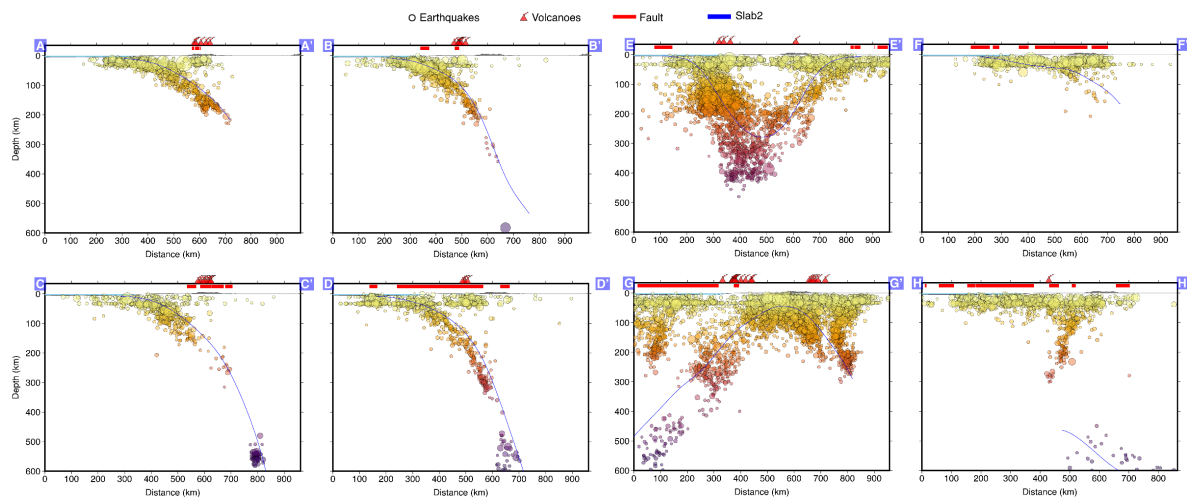


Figure 2. Hypocentres distribution passing through A-A' (western Sumatra), B-B' (southern Sumatra), C-C' (central Java), D-D' (Bali), E-E' (Banda Sea), F-F' (Papua), G-G' (northern Molucca) and H-H' (Sulawesi) regions, Indonesia. All profiles map is shown in Figure 1.

4.1 Updating of Active Faults in Sumatera

New publications of the latest research on active faults and significant number of unpublished reports related to seismic hazard assessments of large engineering construction projects will update the seismotectonic model. The studies conducted by Hady and Marliyani (2020) as well as Daryono et al. (2023a) enhanced our

understanding of the geological and seismological characteristics of this region. Recent paleoseismological studies near the Kerinci Lake and Sipirokareasa added important data on the timing and magnitude of past seismic events. Active fault studies in the western part of the Northern Sumatra revealed a previously neglected active fold thrust belt segment (Natawidjaja et al., 2018).

Based on geological and geodetical measurements Bradley et al (2017) determined the slip rates of the entire Sumatran Fault Zone to be about 12-16 mm/yr. Natawidjaja et al (2018) provided new geological slip rates for the southernmost part of Sumatran Fault segments. More recent studies include Alif et al. (2020) estimating the new slip rate for the eastern and western Semangko fault segments next to the Sunda Strait.

4.2 Updating of Active Faults in Java – Nusa Tenggara

The most significant update for Java is the recent studies and ongoing detailed mapping on the Java active backarc thrust system that runs through highly populated areas in the megacities, including the Capital City of Jakarta, Semarang, and Surabaya, showed in Figure 3 (Aribowo et al., 2022). This fault system was previously called the Baribis-Kendeng Fault. The new studies include discoveries on the active thrust and the blind thrust around and on Jakarta (Aribowo et al, in prep, 2023). The activity of this thrust in Jakarta has also been confirmed by seismological studies (Widiyantoro, S. et al., 2022b; Damanik et al., 2021), and by a recent geodetic-GPS study (Gunawan et al., 2019).

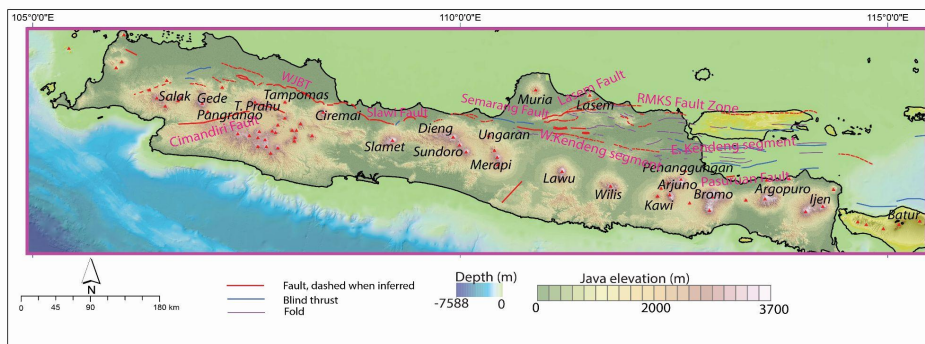


Figure 3. Update active fault map of the Java Island (after Aribowo et al, 2023)

Daryono et al (2018) provided a new detailed fault map, geological slip rate (2-3.5 mm/yr), and paleoseismological data on the Lembang Fault in West Java. Hussain et al (2023) conducted Interferometric Synthetic Aperture Radar (InSAR) and GPS analysis across the same fault and estimated a geodetic slip rate of 4.7 mm/yr (Fig. 4). Other active fault studies include the Mataram Fault (Daryono et al. (2023, b), and the Opak Fault (Pratama et al, in prep 2023) in the Yogyakarta region, and the high-angle normal fault (Pasuruan Fault) in eastern Java by Marliyani et al. (2019).

In the eastern part of Java Island, when it enters the Madura Strait. Both gravity data (Sandwell et al., 2014) and seismic interpretation suggests the continuation of the Eastern Kendeng Hill segment structure, part of the Java backarc thrust system (Aribowo, 2023). The Mw 6.0 thrust event in October 2018 (Patimah et al., 2022) attested to the activity of the Eastern Kendeng Hill Segment. Ongoing active fault research in Madura Island is focused on the re-discovery of the active Somorkoning fault.

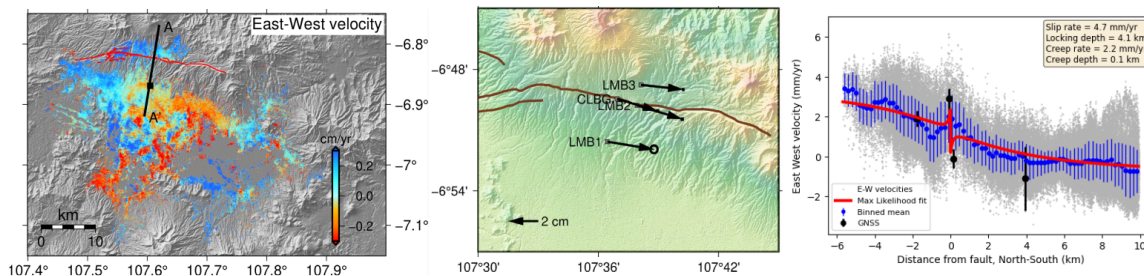


Figure 4. Slip-rate estimation of the Lembang Fault using 6 years of InSAR and 3 years Continuous GPS data (after Hussain et al, 2023).

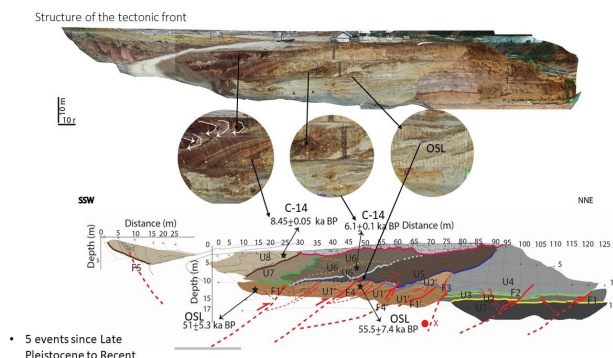


Figure 5. Paleoseismology trenching of the Java Backarc Thrust Fault, Tampomas Segment (modified from Aribowo *et al.*, 2022).

In Bali and Nusa Tenggara there has been an update on active faults evident from Bali to the Wetar backarc domain. In Bali, uplift of the coastal terraces was caused by the activity of the offshore backarc thrust (Felix *et al.*, 2022). In Lombok, the blind volcano-rooted Flores backarc thrust was the source of several episodes of the 2018 Lombok earthquake (Yang *et al.*, 2020; Lythgoe *et al.*, 2021) while coseismic slip derived from GPS study proposed that the 2018 Lombok earthquakes occurred on a parallel fault structure with Flores back arc thrust further south towards Lombok (Gunawan *et al.*, 2023). The Flores Backarc Thrust continues to the Wetar Thrust Fault as the escarpments are detected in bathymetry data, as well as subsurface data (Aribowo, 2023). In addition to the Flores Wetar Backarc Thrust, a new earthquake source was revealed for the 7.3 Mw 2021 event, it was from the Kalaotoa Fault (Supendi *et al.*, 2022).

For the Java megathrust, current discussion concluded that it's segmentation is propose to be changed from five segments in PuSGeN 2017 to four segments for the new map 2023. The updated segmentation is based on seismic and GPS studies by Widiyantoro *et al.* (2020) and Supendi *et al.* (2021), and a geological study by Patria *et al.* (2020). However, based on paleotsunami studies along the southern coast of Java Island (e.g. Harris *et al.*, 2019), it is also possible for the entire Java segment to rupture at once, which would equivalent to a megathrust earthquake of M_w 9,1.

4.3 Updating of Active Faults in Sulawesi, Malucca, and Papua

The September 2018 earthquake in Palu, Sulawesi (M_w 7.5) was followed by significant numbers of post-event active fault and seismological studies and their related publications, which give many new insight to the tectonic and seismic characteristics of the Palukoro Fault and the adjacent Matano Fault. This includes the new detailed active faults and their segmentations (Natawidjaja *et al.*, 2020).

Recent research on the Matano fault, the southeastern continuation of the Palu-Koro fault, showed the fault is capable of generating $M7+$ earthquakes (e.g. Cipta *et al.*, 2017). A study by Patria *et al.* (2023b) has accurately mapped the fault trace of the Matano fault, reconstructed the history of surface-rupturing earthquakes, estimated the recurrence interval of large earthquakes, and calculated the slip rate. Unlike the Palu-Koro fault, the Matano fault records a longer recurrence interval of 200–470 years or 335 ± 135 years, in agreement with the fact that the Matano at ~ 20 mm/yr, half the rate of the Palu-Koro fault (Patria, *et al.*, 2023; Khairi *et al.*, 2020; Walpersdorf, 1998). The slip rate and locking depth of the Matano fault has been investigated based on recent GNSS observation using 20 GNSS campaign stations from 2016 to 2022, maintained by the Geospatial Information Agency of Indonesia, in addition to the Indonesian Continuous Operating Reference Station (InaCORS) (Pratama *et al.*, 2019).

Other new studies in Sulawesi include paleoseismic investigations on the Walanae Fault in South Sulawesi (Jaya *et al.*, 2020), which provided new evidence on the late Quaternary activity of the Fault. This study involves trenching and radiocarbon dating to decipher the history of seismic events along the Walanae Fault.

In Molucca, a recent study in the northern Banda Arc by Patria *et al.* (2021) provided new active fault maps for Ambon and Seram region. They documented comprehensive evidence of the late Quaternary deformation and estimated the potential hazard of active faults in the region. The region largely accommodates the left-lateral motion in eastern Indonesia through the Kawa and Bobot faults. The largest potential magnitude of M_w 7.6 is attributed to the Kawa fault in Seram if its segments rupture simultaneously. However, the impact of an

earthquake due to the Ambon fault could be devastating because the fault is located near a populous region, the Ambon City (Patria et al., 2023a).

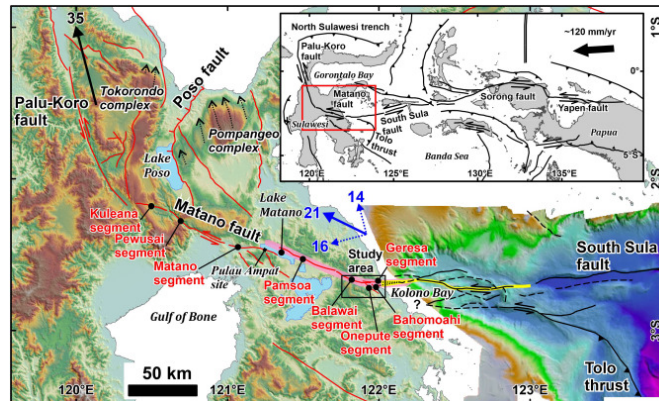


Figure 6. Probable rupture extent (highlighted in pink) of the most recent surface-rupturing earthquake on the Matano fault.

In 2019, a M_w 6.5 earthquake occurred near the city of Ambon, eastern Indonesia, followed by numerous aftershocks with magnitudes ranging of M_L 2-5 at depths of < 30 km (Meilano et al, 2021). This earthquake ruptured an unmapped fault. From GPS analysis, Meilano et al (2021) concluded that this fault has a slip rate of 4.9 mm/yr with a recurrence interval of 115 years. They also analysed the horizontal strain-rate tensor obtained from GPS velocity fields alongside past earthquake records, which indicates that its neighbouring areas are experiencing a significant strain accumulation that aligns with the occurrence of earthquakes with a magnitude equal to or greater than 6.

Zhao et al. (2023) estimated the kinematic block model of the Indonesia-Australia-New Guinea collision zone (IANGCZ). The eastern islands of the Indonesian archipelago which are included in this zone are Papua, Sulawesi, Molucca and Nusa Tenggara islands. The kinematic model defined 23 blocks along with the rotation rates and the block boundary slip rates. Some of the slip rates of the active faults in eastern Indonesia have been updated from this model e.g. Yapen Fault: 36.9 ± 3.9 mm/yr, Tarera Adiuna: 61.3 ± 1.4 mm/yr, Kawa Shear Zone: 23.8 ± 1.2 mm/yr, Banda Detachment: 12 mm/yr. Furthermore, their model also estimated the relative slip rates of the Java Trench to the Timor Trough, demonstrating a gradual decrease in an eastward direction from 65.1 ± 0.3 mm/yr (at 112.4°E) to 10.9 ± 0.3 mm/yr (at 126.7°E). Across this boundary, the slip rates abruptly shift from a southward to south-eastward direction, a shift facilitated by and aligning with the intersection with sinistral motion on the Semau Fault. This progressive alteration in relative velocity and slip direction also appeared in the backarc region, exhibiting a contrary change in motion compared to the megathrust. On the Flores backarc thrust, the slip rate gradually increases eastward, rising from 4.8 ± 0.5 mm/yr at 110.4°E to 29.9 ± 2.0 mm/yr at 126.5°E , this change also influenced by its intersection with the Semau Fault.

Papua Island has long been recognized for its geological complexity and susceptibility to seismic events. However, detailed studies on fault segmentation, a fundamental aspect of earthquake hazard assessment, have been notably lacking. The work from Saputra et al. (2023) fills this crucial gap by mapping and analyzing the fault's segments. This segmentation knowledge is essential for assessing potential seismic risks accurately. By advancing our understanding of fault segmentation, paleoseismology, and kinematics in this region, it equips us with the knowledge needed to enhance disaster preparedness, urban planning, and risk mitigation. This research not only addresses a pressing need for the region but also contributes valuable data to the broader field of earthquake science, benefiting seismic hazard assessments worldwide.

5 Ground Motion Modelling Update

One of the pivotal goals of seismic hazard assessment involves predicting the potential ground motion that could be activated during forthcoming earthquakes. This forecast is traditionally done using empirical formula called a Ground Motion Prediction Equation (GMPE). GMPEs consider parameters such as earthquake magnitude, the distance between the earthquake's origin (seismic rupture) and the location of interest (site), and other elements like local site conditions. The GMPE's reliability highly depends on the quality and quantity

of the underlying database it utilizes, as these equations are generally created via regression analyses performed on observed seismic data. In some regions, GMPEs have been formulated based on simulated earthquake motions.

The GMPEs used in this study refer to the PuSGeN 2017, as shown in Table 1, and we consider updating these with the GMPEs from NGA West-2 and NGA Subduction for the next update of the Indonesia national seismic hazard map.

Table 1. The updated GMPEs for the new update

Shallow crustal fault & shallow background sources	Subduction Interface sources	Subduction Intraslab (Benioff zone) sources
<ul style="list-style-type: none"> Abrahamson et al (2014) NGA West-2 Boore et al (2014) in the NGA-West-2 Campbell-Bozorgnia (2014) NGA-West-2 Chiou-Youngs (2014) NGA West 2 	<ul style="list-style-type: none"> Abrahamson & Gulerce (2020) Interface NGA-Sub Kuehn et al. (2020) Interface NGA-Sub Parker et al. (2020) Interface NGA-Sub Zhao et al. (2006) 	<ul style="list-style-type: none"> Abrahamson & Gulerce (2020) Intraslab NGA-Sub Kuehn et al. (2020) Intraslab NGA-Sub Parker et al. (2020) Intraslab NGA-Sub Zhao et al. (2006)

6 Logic Tree and Softwares

Various earthquake recurrence models were used to characterize the different shallow crustal / subduction zones and planar fault sources in the seismotectonic model. The activity of the source was modelled by fitting a Gutenberg-Richter (1945) truncated exponential curve to the historical seismicity data. The truncated exponential model was used for shallow and deep background sources. We use a characteristic model as proposed by Youngs and Coppersmith (1985) to model occurrence on individual fault segments.

To estimate the maximum magnitude that can be generated by sources we either use method based on observed seismicity and methods based on the use of fault geometries and magnitude scaling relationships (e.g. Wells and Coppersmith, 1994). In this study, the magnitude distribution model used for the probabilistic hazard analysis follows the type of earthquake source models. In the case of fault sources, the Gutenberg-Richter (GR) and Characteristic models are used, as well as for subduction sources. For shallow and deep background earthquake sources, only the GR model is used. The b-value for shallow crustal fault, shallow and deep background is used 1 with the rate (a-value) based on slip-rate for known fault and based on seismicity for background sources. The history of earthquake events around the active faults that have been clearly identified and whose geometry are well modelled is still limited (very rare) so that it is not possible to create a GR trendline from the existing earthquake data, for this reason the b-value is set to a value of 1 for this model, while the a-value is based on slip-rate data which is converted into an earthquake rate.

Fig. 7 shows a schematic of the various magnitude-frequency distributions considered. A truncated-exponential or Gutenberg-Richter (Gutenberg and Richter, 1944) magnitude-frequency distribution between M4.5 to M6.5 is used for shallow background sources and between M4.5 to M7.8 for the deep background sources (Benioff zone) to model rates for different sizes of earthquakes in each grid cell or zone. The recurrence intervals of faults and subduction models vary between M6.5 to Mmax (each fault), both truncated exponential (GR) and characteristic models (char) with weighting of 34%: 66% for faults and 50%: 50% for subduction sources, respectively. The b-value for the subduction source is determined by taking historical earthquake data in the megathrust area, and then statistical analysis is carried out with the maximum likelihood model.

The uncertainty assessment in this study is performed using a logic tree methodology. The epistemic uncertainties are estimated using Monte Carlo sampling techniques to generate a number of epistemic branches reflecting the range of possibilities, according to the available data and the methods adopted to define quantitative values and their associated uncertainties. The aleatory uncertainty is the standard deviation associated with the ground motion predicted by the attenuation relationships. The distribution of acceleration values for a given magnitude and distance is assumed to follow a lognormal probability function. Both epistemic

and aleatory uncertainties are propagated in this study through a coupled methodology combining a logic tree as used in PuSGeN 2017.

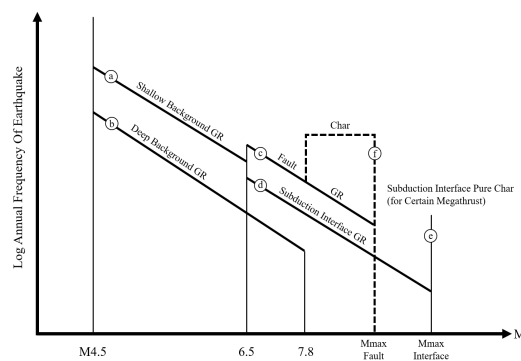


Figure 7. The different types of magnitude-frequency distributions used for different source types (after Irsyam *et al.*, 2020).

For the software, PuSGeN has updated by adding GMPE NGA West-2 and NGA Subduction to the PSHA software from USGS (Fortran code), this software together with OpenQuake from GEM is used for the purpose of updating the latest Indonesian hazard map. EZ-FRISK 8.10 from Fugro is also used to check the hazard value results from the two software above at several location points or cities. This are done to ensure that the same input parameters will produce very similar hazard values.

7 Conclusions

Prevention and mitigation efforts related to creating earthquake-resistant building infrastructure have been carried out by the PUPR along with collaboration with PuSGeN by preparing, compiling and formulating standards in the fields of science, structure and building construction, both compiling new standards and updating existing standards in accordance with advances in science. The latest knowledge and technological developments are conditioned by the increasing level of earthquake hazard vulnerability.

In summary, updating the entire active fault map in Indonesia through geological, geomorphological, and geophysical methods is not only a matter of scientific importance but a critical step toward safeguarding the lives and well-being of the Indonesian people. It represents a collective effort effort from academicians, scientists, government, international communities and stake holders to to reduce earthquake-related risks, enhance resilience, and promote sustainable development in a region prone to seismic activity.

8 Acknowledgment

The studies is made possible with the multi-institution collaboration, data and funds from The Ministry of Public Works and Housing of Indonesia; Indonesian Meteorology, Climatology, and Geophysical Agency; National Research and Innovation Agency; Geological Agency, Ministry of Energy and Mineral Resources; Geospatial Information Agency; Indonesian Ministry of Education and Culture under World Class University (WCU) Program; Bandung Institute of Technology; Gadjah Mada University; Sepuluh Nopember Institute of Technology; University of Indonesia; National Institute of Science and Technology; National Institute of Technology; Universitas Pembangunan Nasional Veteran Yogyakarta; with the international support from Cambridge University, UK; Australian National University, Australia; US Geological Survey, USA; Global Earthquake Model Foundation, Italy; and British Geological Survey, UK. EH publishes with permission from the Director of the British Geological Survey.

9 Contributions

MI, SW, LF, NRH, DHN developed the framework. DHN lead the geological studies with MD, AP, SA, GIM, ARP, AP, MH, DDW, S, AW, BS, and CP. AND lead the geophysics studies with SR, PS, NH, M, ASP, AA, and MR. IM lead the geodetic studies with EG, NRH, GHP, AA, CP, IMA, PM, HK, SR, AFS and EH. MA, WT, HH, FA, Hy conducted the GMPE and SHA studies. MP, PC, MP, EH reviewed the manuscript.

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