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Smoothed Gridded Seismicity Effect for Land-Use Development, Case Study: Kalimantan Island, Indonesia

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Preliminary communication

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Abstract

Smoothed gridded seismicity is an analysis model in seismicity that allows for the obtaining of a rate based on the b-value and the same magnitude range. The data study has been collected and analyzed from a background source gathered by PusGen, referred to as the PusGen catalogue, with approximately 70 thousand data points. Two software programs (i.e. USGS PSHA and OpenQuake) were utilized in this study, and both programs have been proven as reliable in the creation of the 2017 Indonesia Earthquake Hazard Map. The final steps are to compare the acceleration map results with the Kalimantan Island land-use map and to analyze suitability development planning against potential hazards and earthquake risks. The results stated that: (1) acceleration due to the shallow background earthquake for the Kalimantan region, range from 0.00-0.25g (using USGS PSHA) and 0.0-0.4g (using OpenQuake); (2) meanwhile, based on the deep background earthquake source, the maximum accelerations that occur are 0.15g and 0.25g when using USGS PSHA and OpenQuake, respectively; (3) the utilized of land-use for the current and future years is in line with the results of the acceleration simulation. The study recommends to take into account the seismic aspects in new planning of the capital city, mining and residential areas in order to reduce the existing risks.

Keywords:

smoothed gridded seismicity; earthquake background source; land-use; Kalimantan Island

1. Introduction

Smoothed gridded seismicity is one of the analysis models in seismicity that allows for the obtaining of a rate (namely a-value) based on the b-value at the same magnitude range. The variation of different earthquake events for each area is illustrated with different rate values. This rate is based not only on earthquakes in the selected zone area but also on their surroundings (**Akinci et al., 2018; Hiemer et al., 2014**). This method is applied to background earthquake sources. Background source is a term that refers to an earthquake source with no apparent or definite mechanism (**Ghasemi et al., 2020; Irsyam et al., 2020**). This study is limited to a magnitude of 4.5 <= Mw <6.5 for depths up to 50 km and the rest Mw> = 4.5. This assumption is in line with the calculation of earthquake background sources in Indonesia, especially in forming the 2017 Indonesian Earthquake Hazard Map (**Irsyam et al., 2020; PusGen, 2017; Syahbana et al., 2020**). Smoothed gridded seismicity is a method to complement the shortcomings of the area source method, which with the gridded method, divides the area into smaller ones to minimize the chance of seismic parameter errors in the specific zone. To conduct the smoothed gridded seismicity calculation, two software programs were utilized in this study. Both programs have been proven as reliable in the creation of the 2017 Indonesia Earthquake Hazard Map, i.e. USGS PSHA and OpenQuake and will be explained further in the method section. PSHA stands for Probabilistic Seismic Hazard Analysis, a method for calculating earthquake hazard that considers the probability of magnitude, distance and acceleration that may be exceeded. In this study, 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; Omang et al., 2016; Grunthal & Wahlstrom, 2001**).

Kalimantan Island is one of the largest islands in Indonesia and has an excellent opportunity to become a destination for relocating the Indonesian capital city from Jakarta to *Panajam Paser Utara* and *Kutai Kar-*

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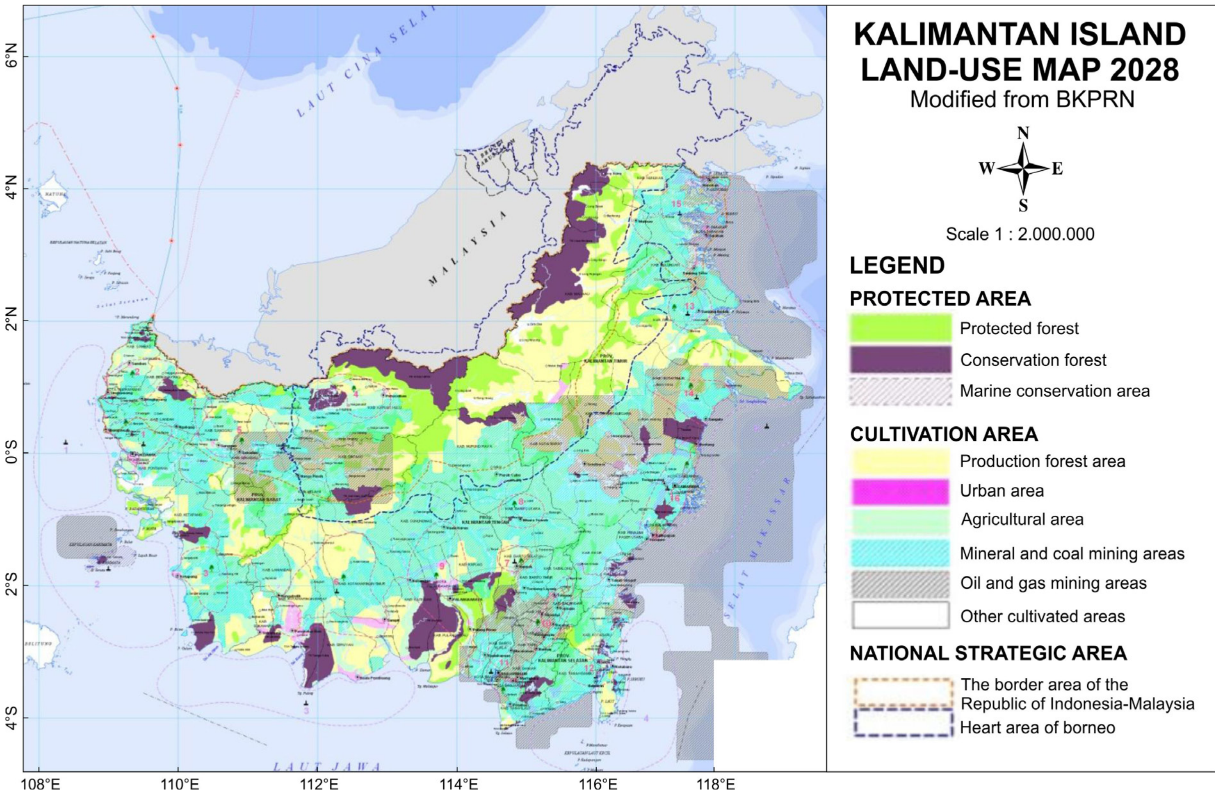


Figure 1: Kalimantan Island Land-use Spatial Plan in 2028

tanegara. In general, although this island only has a slight potential for earthquake hazard, its effects must be considered, especially if it is related to existing land-use and future development planning. The National Land-use Spatial pattern (Law Number 26 of 2007 Concerning Spatial Planning) has three parts: protection, cultivation and national strategic areas. The objectives of spatial planning for the national territory are to achieve several things, including: (1) national territorial space that is safe, comfortable, productive, and sustainable; (2) harmony between the natural and the artificial environments; (3) the integrated use of the land, sea, and air space, including space in the earth; (4) integration of spatial planning for national, provincial, and regency or city areas; (5) sustainable use of natural resources for the improvement of community welfare.

Continuing the spatial pattern of Kalimantan Island for the year 2028 is the distribution of spatial use in the form of protection and cultivation functions for the economic development of forestry, plantation, agriculture, and mining based on sustainable management with due regard to biodiversity. The spatial structure of Kalimantan Island is a hierarchical arrangement of urban-centres bound by an infrastructure system (transportation network system, telecommunications, energy, and water resources). Those urban-centres will be more scattered in the centre and along the coast of the island.

According to BKPRN (National Spatial Planning Coordinating Board) and President Decree No. 3 of 2012 concerning RTR for Kalimantan Island, until 2028, the island of Kalimantan will own 70 percent of the cultivated area, while the protected area will cover 30 percent of the island of Kalimantan. Cultivation areas will be spread out along the horizontal-axis island (west-central-east), while protected areas are spread north and south (see **Figure 1**). The spatial planning objectives for the development of the Kalimantan Island area: (1) "Lungs of the World" with the preservation of biodiversity conservation areas and protected function areas with vegetation of wet tropical forests at least 45 percent of the area of Kalimantan Island; (2) energy independence and national energy storage for electricity; (3) centre for the development of mineral, coal and oil and natural gas mining; (4) development centre for sustainable oil palm, rubber and forest product plantations; (5) the front border and gateway of the Republic of Indonesia with the State of Malaysia; (6) (7) development of tropical wet forest ecotourism areas and Kalimantan culture; (8) integration of intermodal transportation network systems that can increase inter-regional connections and open regional isolation; (9) self-sufficiency and national food storage. Future prediction, the eastern province, *Penajam Paser Utara* (North Penajam Paser) and Kutai Kartanegara region will be created as a new capital city to replace the role of Jakarta city (see **Figure 2**).

The development of land-use zoning is a crucial activity seen from various aspects, such as population density, economic equality, natural resources, including natural hazards in the form of earthquakes (**Armaş, 2012; Cosentino et al., 2018; Prayitno et al., 2020;**

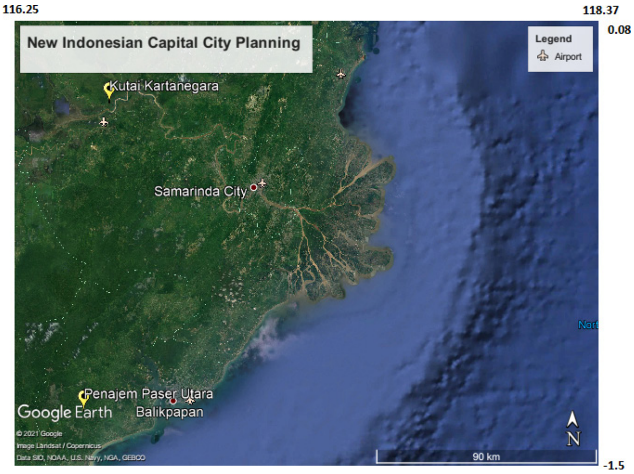


Figure 2: Location of new Indonesian capital city planning. Both *Kutai Kertanegara* and *Penajem Paser Utara* are in the East Kalimantan Province.

Rashed & Weeks, 2003; Taylor & Thrift, 2012; Wu et al., 2017). A background source earthquake as one of the earthquake mechanisms that is included in the above aspect. Therefore, as an improvement method to analyze this source (formerly area source), smoothed gridded seismicity is utilized to calculate the hazard in this area (**Stirling et al., 2002; Werner et al., 2010; Zechar et al., 2013**). Moreover, earthquake hazard analyses in Kalimantan Island are rarely done due to the small number of events recorded to date. Mistakes in considering some of these aspects will result in ineffective spatial planning or land-use objectives.

The novelty in this study is to analyze the region with a focus on the dominant earthquake source in the area, i.e. the background earthquake source. The challenge is how to make a background earthquake source to be used in analyses following the prevailing rules, starting with the declustering and completeness processes. In this study, a module has been made in Python to carry out this process to be further processed using OpenQuake software. Meanwhile, the USGS PSHA software is processed using the ZMap based on Matlab.

This study described the relationship between regional land-use planning with earthquakes, especially background earthquakes. In this paper, the authors divided the materials and methods into several subchapters, i.e. location, data, software used, and workflow. The location area study will be briefly explained correlated with seismicity conditions. Data used here was also described before and after the declustering process. Moreover, in this study, the software and workflow applied study is also being explained.

2. Materials and Methods

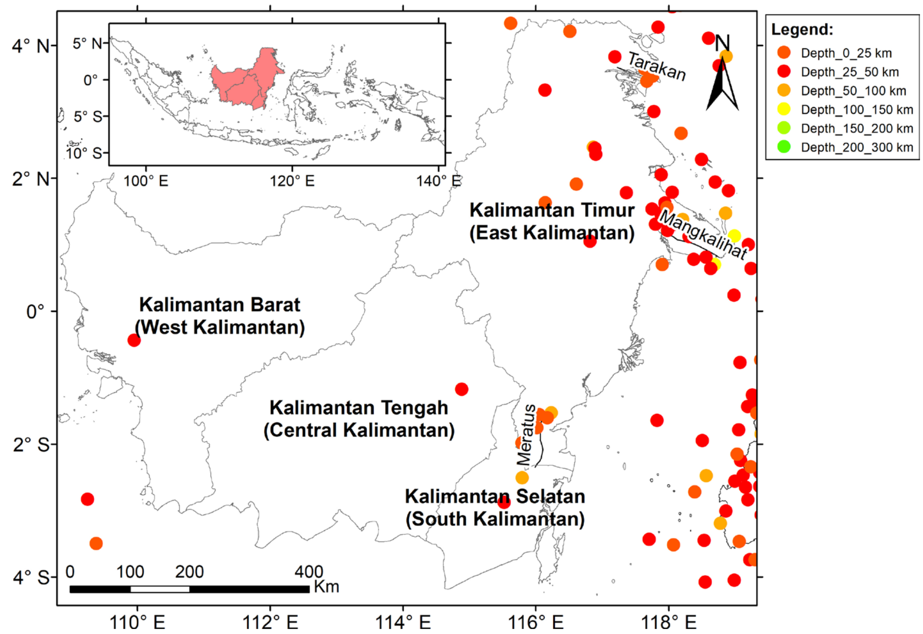
The area used in this study is 0.1 ° x 0.1 ° and uses a Gaussian distribution over a 150 km radius (**Akinci et al., 2018; Hiemer et al., 2014; Moschetti et al., 2014; Werner et al., 2010**). Smoothed gridded seismicity is a critical study that complements the previous method, which is considered more biased, namely the source area. In the source area, those boundaries of areas that are considered to have a homogeneous level of seismicity are still being debated because it is possible that these boundaries would be different for each researcher (**Ide et al., 1996; Woo, 1996**). Smoothed gridded seismicity analyses the area in small parts with different rates due to the earthquake background source.

2.1. Location

Kalimantan is one of the largest islands in Indonesia with coordinates between 4.836570° north latitude - 4.876377° south latitude and 108.412472° - 119.130835° east longitude. Kalimantan is an exciting location because this study area has essential national assets in mining, forestry, settlement, and even a discourse as a destination for moving the capital city of Indonesia in the future. Furthermore, this area has minimal earthquake sources compared to other locations in Indonesia. Indonesian locations, in general, have earthquake sources originating from faults, subduction, and megathrust. As seen in **Figure 3**, Kalimantan Island has an earthquake source dominated by the background. Therefore, this study will focus on the background earthquake to be analyzed using the two selected software programs. Additionally, an evaluation of the relationship between seismicity and land-use will be carried out to determine whether the development and land-use have been implemented correctly.

The Kalimantan island is composed of various bedrock, which are of continental, oceanic, and transitional origin (**McClay et al., 2000; Parkinson et al., 1998; Satyana et al., 1999; Wakita et al., 1998**). The Barito Basin in the southern part of Kalimantan is located on the Schwaner bedrock of continental origin in the western part. The eastern part of Kalimantan Island is based on the accreted crust from the Meratus Mountains. To the north, the Kutai Basin is bounded by accreted crust from Tinggian Kucing (part of the Central Range) and bedrock from the Mangkalihat continent in its western and northern parts. The Tarakan Basin, which is further north than Kutai, is bounded by the accreted crust Dent-Semporna, Tinggian Sekatak-Berau, the basement from the continent of Mangkalihat. These basement terrane relationships are not fully understood. Some of these boundaries may be sutures indicating traces of collision zones or significant fault zones (**Metcalfe, 1996; Van De Weerd & Armin, 1992**). Earthquakes are relatively rare on Kalimantan Island.

However, on June 5, 2015, an earthquake with a magnitude of 6 Mw occurred in the Ranau area, Sabah, which resulted in 19 fatalities, landslides on Mount Kinibalu and damage to buildings in the city of Ranau. Based on the Meteorology, Climatology and Geophysics Agency (BMKG) records, before the incident, an earth-



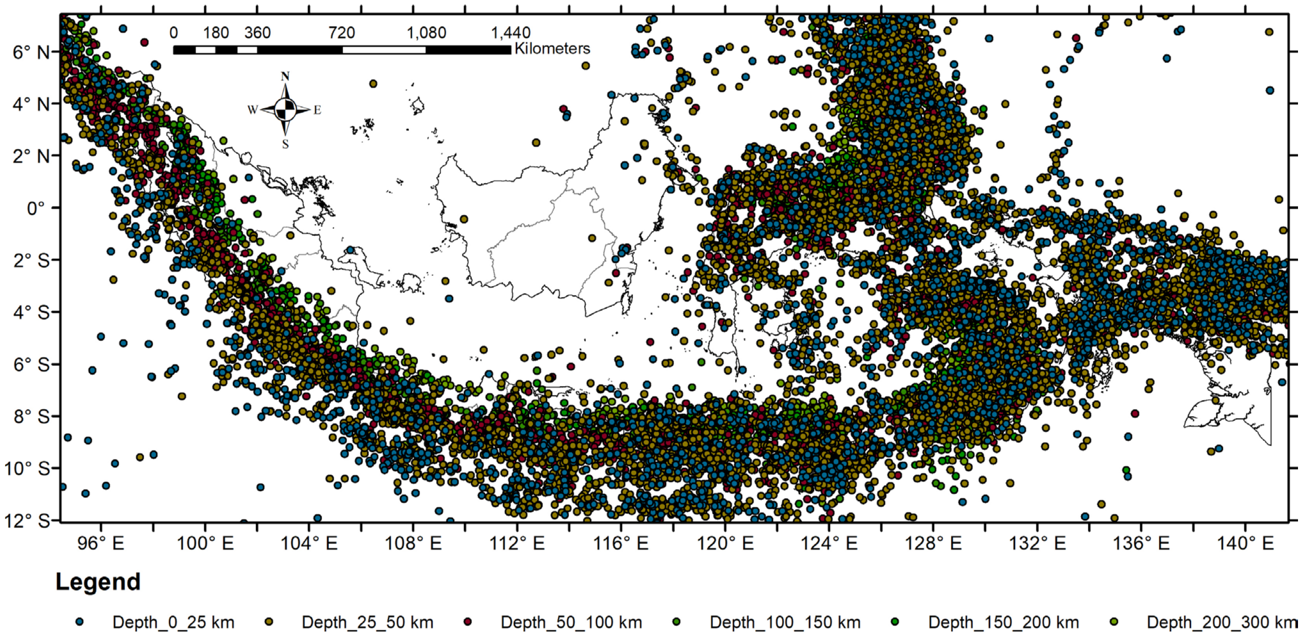


Figure 3: Seismic background sources on the Kalimantan Island (above) and in Indonesia (below) (**PusGen, 2017**)

quake with a magnitude of 5.7 Mw was also recorded on February 25, 2015, with an epicenter 413 km northeast of the city of Tarakan. This event indicates that Kalimantan is not entirely earthquake-safe, as many people understand. Geologically and tectonically, especially in the East Kalimantan Province, there are three earthquake source fault structures: Meratus Fault, Mangkalihat Fault, and Tarakan Fault. BMKG said the results of monitoring of Meratus Fault and Mangkalihat Fault in the Berau Regency and East Kutai Regency showed that they are still very active. Shaking phenomenon was recorded in the East Kalimantan region, which was shaken by damaging earthquakes seven times, namely in 1921, 1964, 1982, 1983, 2000, 2006, and 2007. These earthquakes had a magnitude above 5.0 Mw, and some tsunami followed. Shocks caused by the earthquake originating from the Mangkalihat Fault can impact the MMI VI-VII intensity scale. The VI-VII MMI intensity scale means that an earthquake that occurs can cause moderate to severe damage.

2.2 Data

The data collected to be analyzed in this study was data collected by PusGen, referred to as the PusGen catalogue (PusGen, 2017), with approximately 70 thousand data points. The data used is the magnitude of each earthquake and its location, depth and time of occur-

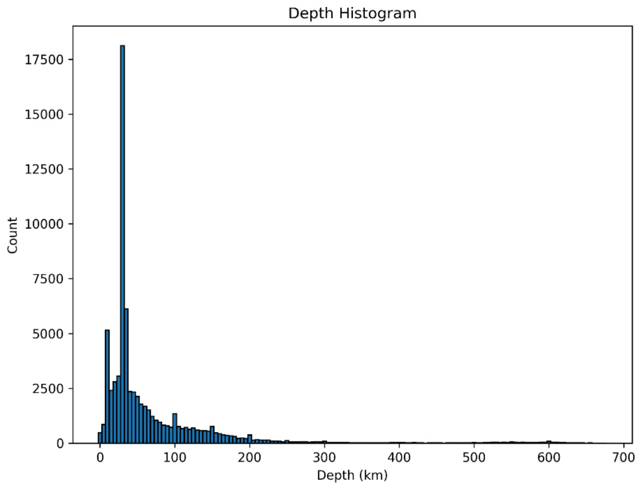


Figure 4: Number of earthquake events before declustering for the Indonesian region in terms of number of events vs. depth

rence. The existing earthquake units have been uniform, namely Mw. This data is a collection of several research results from teams and agencies such as The International Seismological Center (ISC), The National Earthquake Information Center-United States of Geological Survey (NEIC-USGS), earthquake catalogues that have been relocated by (Engdahl et al., 1998, 2007) and the catalog of relocated BMKG hypocenters of (Nugraha et al., 2018a).

In **Figure 4**, there is a dominant source at a depth of fewer than 50 km, which is associated with the term shallow background. At a depth of fewer than 50 km, the existing earthquake sources consist of active and background fault sources. On the other hand, the number of earthquakes with greater depths appears small, less than 50 percent of the earthquakes recorded in this catalog. This phenomenon is caused by the source of the internal background earthquake comes from the Benioff zone.

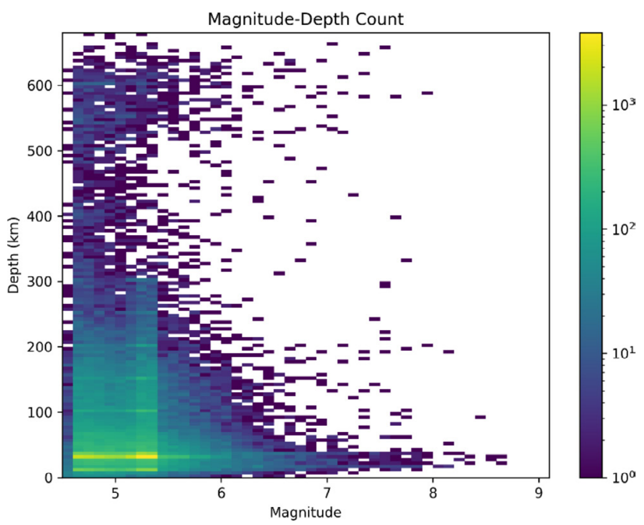


Figure 5: Distribution of data used in the PSHA analysis for all of Indonesia in terms of magnitude vs. depth

This zone is a continuation of the megathrust/subduction zone where the mechanism is more internal to the continental crust, so it is often referred to as intraslab (**Passarelli et al., 2018**).

From Figure 5, the distribution of magnitudes in Indonesian regions in general can be seen. Earthquake events with varying magnitudes from 4.5 to 8 + Mw vary more at depths below 100 km, and a higher number is at magnitudes less than equal to 5.5 Mw for that depth. This occurrence indicates that many shallow earthquakes occur in Indonesia. In contrast, earthquakes with a depth of more than 300 km were also recorded here, but in small numbers.

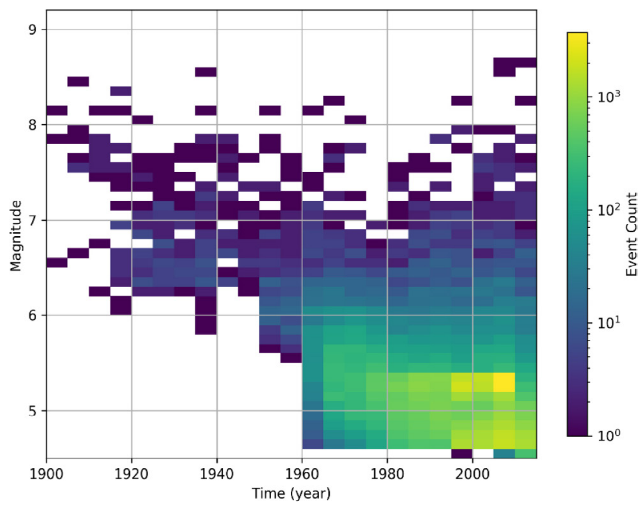


Figure 6: Distribution of data used in the PSHA analysis for all of Indonesia in terms of magnitude vs. years

Meanwhile, in **Figure 6**, the earthquake data recording before 1960 shows a small number and is limited to a magnitude greater than 6 Mw. After 1960, earthquakes occurred with a magnitude of less than 6 Mw were recorded at a significant amount. This finding is well correlated with the increasing sophisticated seismometer devices capable of recording earthquake energy to a minimum level (**Nugraha et al., 2018a; Nugraha et al., 2018b**).

2.3 Software

Two software programs (USGS PSHA and OpenQuake) have been proven as reliable in the creation of the 2017 Indonesia Earthquake Hazard Map (**PusGen 2017**). USGS PSHA is a software program released by the USGS (United States Geology Survey). In this program, several modules are used for seismic processing. The agridMLsm and HazgridXnga modules were used for this analysis. The version used is the 2014 version with modifications to the attenuation equation (GMPE / Ground Motion Prediction Equation), namely: Boore et al. 2014, Campbell Bozorgnia 2014, and Chiou Young 2014. Updates related to the open source's advantage include, namely, the Fortran language program Fortran (**Boore et al., 2014; Campbell & Bozorgnia, 2014; Chiou & Youngs, 2014; Harmsen, 2007**).

Likewise, OpenQuake is a tool that can be downloaded freely and results from a collaboration of a group of researchers in the Italian region (**GEM, 2020; Pagani et al., 2014; Silva et al., 2014**). There are also many modules in this program. For these purposes of study, a module that aims to create a background earthquake source is used to process the hazard calculation with a classical calculator for the PSHA.

2.4 Work steps

The work steps taken are as follows: (1) in OpenQuake, the catalog data obtained was first processed with a module made in Python language, including declustering, completeness, and rate calculation with a Gaussian distribution, continued by data processing via a classical calculator in OpenQuake; (2) in the USGS PSHA, the processed data was declustered using ZMap.

Table 1: Recapitulation of background earthquake declustering process

No	Depth (km)	Before	After	Reduction (%)
1	0-25	12163	2365	80.55578
2	>25-50	31716	7122	77.54446
3	>50-100	13091	5137	60.7593
4	>100-150	6670	2904	56.46177
5	>150-200	3619	1768	51.14673
6	>200	3459	1281	62.96618
	Total	70718	20577	70.90274

The rate was calculated using the agridMLsm module, and the acceleration value was calculated using hazgridXnga. The GMPE used is based on the logic tree utilized in the 2017 Earthquake map: Boore et al. 2014, Campbell Bozorgnia 2014, and Chiou Young 2014; (3) The final step is to compare the acceleration map results with the existing spatial map of Kalimantan Island. This study analyzes the suitability of development planning against potential hazards and earthquake risk in discussion section.

3. Results

The data above is combined earthquake data foreshock, mainshock and aftershock. After declustering with the Gardner and Knoppof method (**Gardner & Knopoff, 1974**) and completeness (**Nasir et al., 2013**), the results are shown in the **Table 1**. From **Table 1**, the reduction due to declustering and completeness is considerable, even exceeding 50 percent. This finding is due to seismometer sensitivity and tectonic conditions in Indonesia, which may differ from other regions.

The analysis using OpenQuake and USGS PSHA software can be seen in **Figures 7-10**. Processing at the USGS PSHA begins with preparing background earthquake input by dividing the mainshock earthquake source into six depths (0-25, 25-50, 50-100, 100-150, 150-200, and 200-300 km). Subsequently, smoothing gridded seismicity was carried out with the Gaussian function, which considered the effect on the surrounding grid with a distance of up to 150 km to calculate the rate on those grids (**Frankel, 1995; Petersen et al., 2008**). Then, the acceleration value was calculated based on the

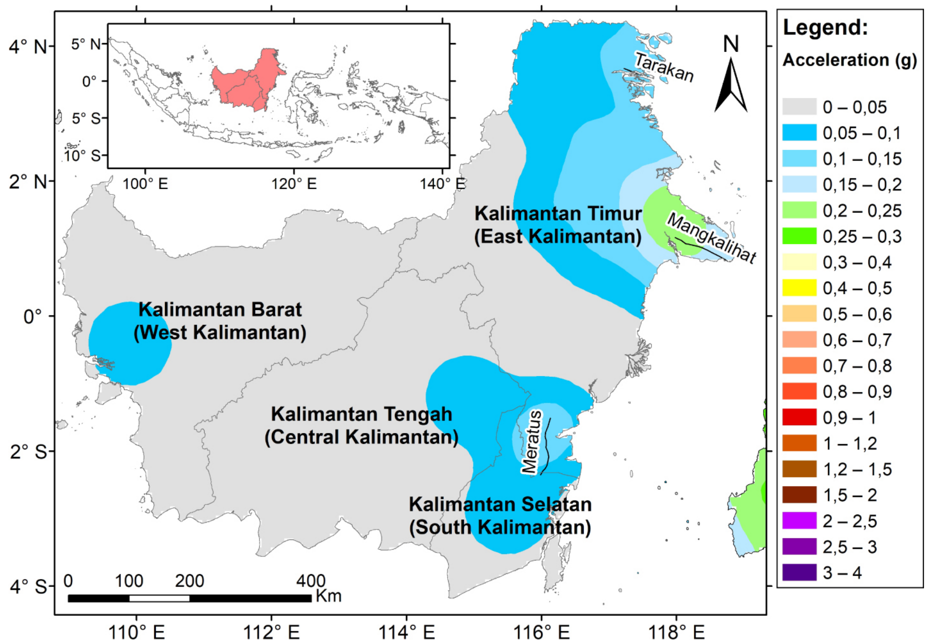


Figure 7: Results of analysis with the USGS PSHA 2 percent return time in 50 years of shallow background earthquake sources

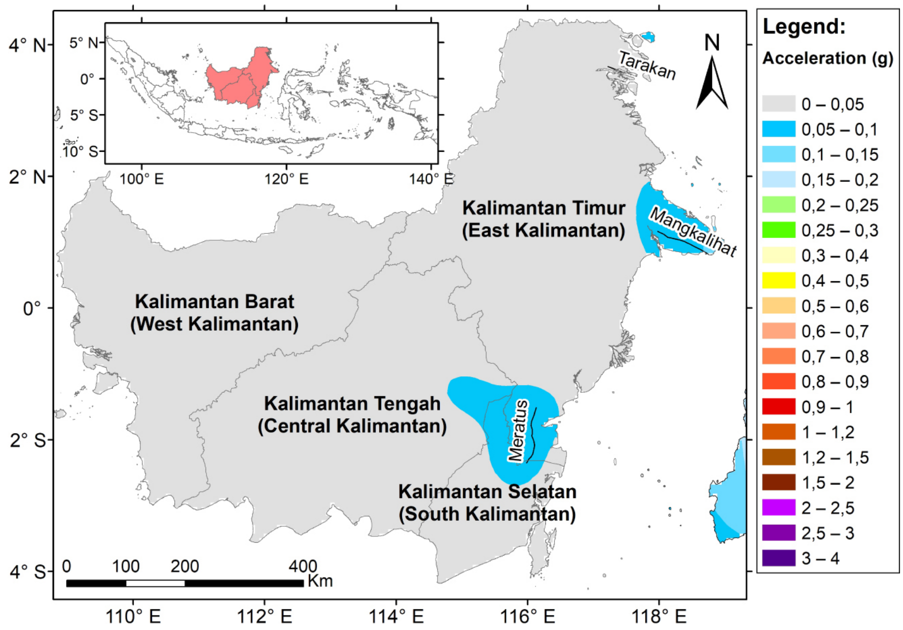


Figure 8: Results of analysis with USGS PSHA return period exceeded 2 percent in 50 years of deep background earthquake sources

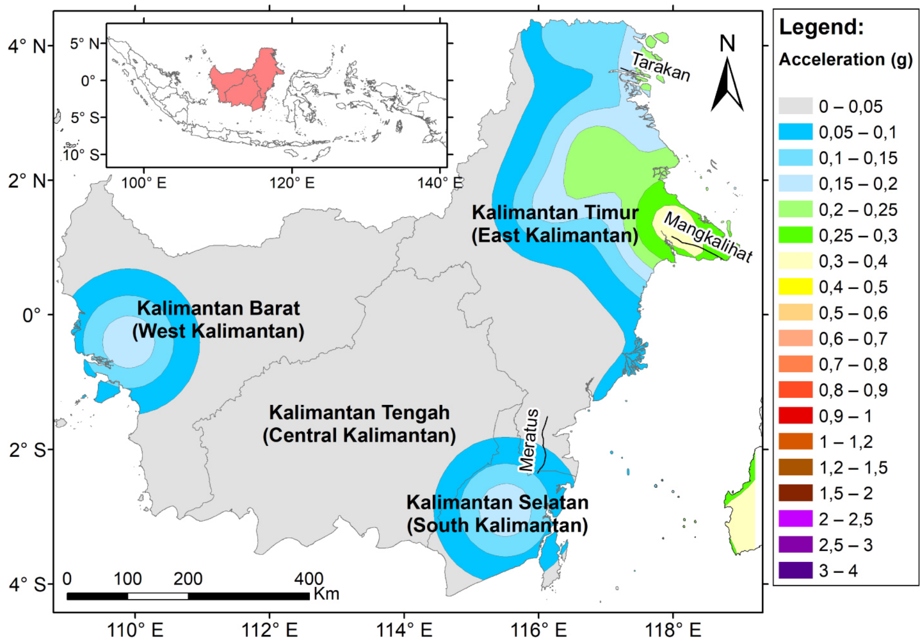


Figure 9: Results of analysis with OpenQuake return time exceeded 2 percent in 50 years of shallow background earthquake sources

current rate using existing attenuation equations and individual weights deemed appropriate to Indonesian conditions.

It can be seen from the shallow earthquake analysis that there are zones that are centered on several areas, such as in the eastern part of East and South Kalimantan and the western part of West Kalimantan. Meanwhile, in other areas, there is no significant acceleration value.

The acceleration caused by the deep seismic mechanism presented in the Figure 8 shows us what it looks like on the east side, in either East or South Kalimantan Provinces.

There is no significant difference between the deep background earthquake source acceleration values from two software programs, as depicted in the **Figure 10**. In the results, OpenQuake was formed on the eastern side of East Kalimantan and part of Central Kalimantan and South Kalimantan's border. Meanwhile, the USGS PSHA was formed in the same area, but the coverage area is more extensive than OpenQuake.

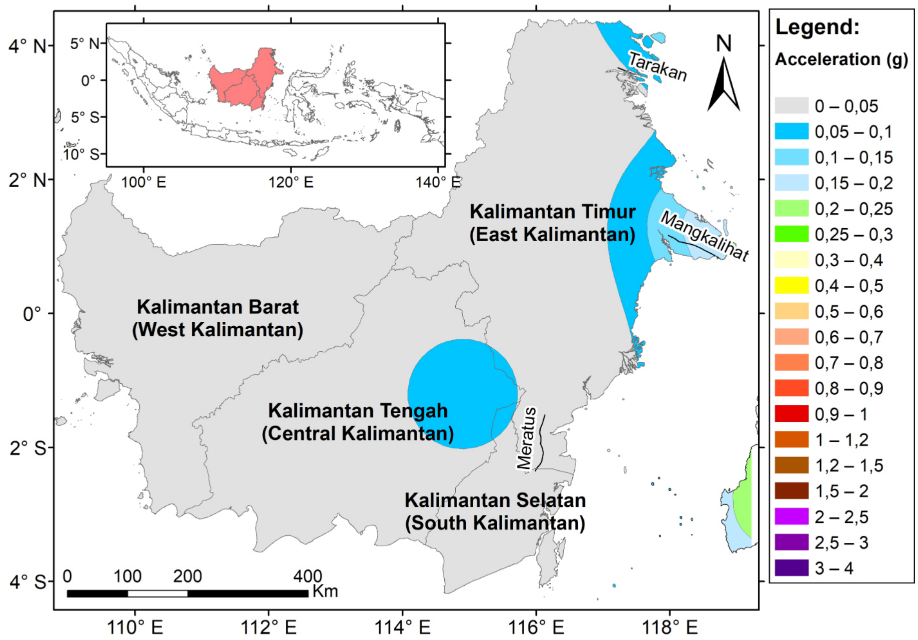


Figure 10: The analysis results with OpenQuake return time exceeded 2 percent in 50 years of deep background earthquake sources

4. Discussion

The exciting findings from **Figure 8** can be observed here. This phenomenon is quite questionable due to the absence of a well-identified Benioff zone around Kalimantan Island's eastern side. There is a suggestion about this condition that it could be due to the earthquake source on the farther side, namely north of Sulawesi Island, or other mechanisms caused by fluid activity under the crust (**White et al., 2019; Zhao et al., 2017**).

By using OpenQuake software, the results of the acceleration calculations are more extensive on the same side as those calculated with USGS PSHA (see **Figure 9**). The pattern that is formed also has similarities in the area where the acceleration parameter increases. This result is reasonable because there is a bias in the numerical process carried out by Python and Fortran, coupled with the interpolation process in contour formation.

Based on the simulation results of the earthquake acceleration and spatial planning and Kalimantan Island area, the various conditions that exist can be seen. First is a discussion of shallow and deep background earthquakes. A shallow background earthquake is an earthquake that is influenced by an unclear mechanism with a hypocenter depth of fewer than 50 km, and a deep background is the result of Benioff's source being at a deeper depth of up to 300 km (**Irsyam et al., 2020; Syahbana et al., 2020**). The calculation shows that the highest acceleration value is in the eastern edge of East Kalimantan Province. Meanwhile, there is an acceleration of 50 percent of the maximum value in West Kalimantan Province for shallow sources and Central and South Kalimantan for deep sources in other areas. It can be seen from **Figures 7-10** that the shallow background earthquake sources dominate the study area more than the deep one. This fact is evident from the seismotectonic Kalimantan region, which has none of the Benioff zone around it. The closest Benioff zone in the Kalimantan area is north of Sulawesi Island. Second is a discussion of spatial planning on the island of Kalimantan in the present and in future conditions. In the explanation found in the previous chapter and as seen in **Figure 1**, the National Spatial Planning Coordinating Agency states that the East Kalimantan province on the east coast is used for forestry and mineral mining, and the south and central borders of the Kalimantan provinces for forestry and agriculture. Lastly, the west coast of West Kalimantan is used for natural tourism parks, forests, and settlements.

Moreover, substantial attention is given to the mine planning on the east side due to an earthquake with an acceleration on the bedrock of 0.4g and the residential side with a maximum acceleration of 0.2g. According to the planning of the capital city relocation, from the earthquake hazard side, those areas are predicted to experience an earthquake acceleration of up to 0.1g, as described in **Figures 9** and **10**. According to **Trifunac & Lee** (**1992**), this site will experience shaking, as previously mentioned, at level VI of MMI. Furthermore, the cause of that needs some engineering countermeasure so that the infrastructure will remain during a hazard. According to the National Board for Disaster Management (BNPB in Indonesian), losses due to the earthquake during 1815-2019 regarding earthquakes reach USD 3382. This number is quite enormous in such an area with a sparse population (BNPB, 2021). Furthermore, based on a national discussion organized by the Ministry of National Development Planning / Bappenas with the title "Towards a Future Capital: Smart, Green and Beautiful," then if there is a planning failure in relocating the capital city, it will endanger around 15,801,800 people (not including those who move from outside Kalimantan) and a financial loss of at least USD 32.9 billion.

As a result, serious attention needs to be emphasized on slope stability, whether in closed or open types, building structures, and the types of materials available for settlements (**Irsyam et al., 2018; Umar et al., 2014**). Based on the lowest fatality earthquake, which is suspected to be due to the material of a common village house called "Lamin" (**Fajarini & Ratniarsih, 2019; Mulyoutami et al., 2009**). This house is made of wood, while wood itself is well-known as a good material to absorb impulse energy, such as an earthquake. Apart from that, modern development in society will always occur, including house models and material changes. Recently in Indonesia, homes have been constructed from brick and concrete. Since these buildings behave differently when exposed to earthquake energy, it is necessary to design and plan the construction of earthquake resistant buildings. A further problem that needs to be taken into account is the propagation of earthquake waves from the bedrock to the surface, often termed wave propagation. This wave propagation will result in an amplification or deamplification event, namely an enlargement or reduction of the acceleration value. To carry out this study, it is necessary to also examine the site class on Kalimantan Island, as a whole, using the Vs30 parameter as regulated in the Indonesian National Standard (SNI) for geotechnics and SNI for Building Planning against seismicity. Vs30 is an engineering parameter that shows the average shear wave velocity from the ground to a depth of 30m. This parameter is one of the essential variables in seismic analysis, one of the examples is related to the amplification of acceleration, velocity or displacement (**Badan Standard Nasional, 2017; BSN, 2019; Hata et al., 2010; Syahbana et al., 2019; Syahbana et al., 2018; Yuliastuti et al., 2021**). Based on the results of this study, it is also recommended to analyze other models to predict the level of earthquake activity, for example, using the Markov Chain model that has been applied to the Algerian region (**Dahmoune & Mansour, 2018**). Thus, the level of earthquake activity with several models can be observed to obtain a more comprehensive understanding. Meanwhile, land-use for forests and agriculture does not require serious attention due to earthquakes, except this region located in a hilly area.

5. Conclusions

Seismic studies associated with the evaluation of the spatial land-use of an area are vital. In this study, a seismic analysis was made with a 2 percent return period exceeding 50 years using two open source software programs. This study involves a background earthquake source, which is the dominant earthquake source on the island of Kalimantan. Both software programs show several zones with a maximum acceleration in Kalimantan Island's east and west areas. Shallow background results in higher acceleration than deep ones. Using OpenQuake, the acceleration value is up to 0.2g on the coast of West Kalimantan and 0.4g on the east coast of East Kalimantan, whereas USGS PSHA calculated only 0.1g and 0.25g for the respective area. The area is planned to be a new capital city, mining and residential area, while the areas with a lower acceleration are used as plantation and forestry areas. According to the MMI scale, the new planning capital city will be up to about 0.1g in acceleration or level VI. Therefore, it is necessary to conduct a more comprehensive study in the planning of the new capital city, mining and residential areas by considering the potential hazard of earthquakes based on the available data.

6. References

Akinci, A., Moschetti, M. P., and Taroni, M. (2018): Ensemble Smoothed Seismicity Models for the New Italian Probabilistic Seismic Hazard Map. Seismological Research Letters, 89(4), 1277–1287.

Armaş, I. (2012): Multi-criteria vulnerability analysis to earthquake hazard of Bucharest, Romania. Natural Hazards, 63(2), 1129–1156.

Badan Standard Nasional. (2017): *Persyaratan perancangan geoteknik* [Geotechnical design requirements].

BNPB. (2021): Indonesia Hazard Data and Information. https://dibi.bnpb.go.id/DesInventar/profiletab.jsp

Boore, D. M., Stewart, J. P., Seyhan, E., & Atkinson, G. M. (2014): NGA-West2 equations for predicting PGA, PGV, and 5% damped PSA for shallow crustal earthquakes. Earthquake Spectra, 30(3), 1057–1085.

BSN. (2019): SNI 1726:2019 *Tata Cara Perencanaan Ketahanan Gempa untuk Struktur Bangunan Gedung dan Non Gedung* [Earthquake Resistance Planning Procedures for Building and Non-Building Structures]. 1, 238.

Campbell, K. W., & Bozorgnia, Y. (2014): NGA-West2 ground motion model for the average horizontal components of PGA, PGV, and 5% damped linear acceleration response spectra. Earthquake Spectra, 30(3), 1087–1115.

Chiou, B. S.-J., & Youngs, R. R. (2014): Update of the Chiou and Youngs NGA model for the average horizontal component of peak ground motion and response spectra. Earthquake Spectra, 30(3), 1117–1153.

Cosentino, C., Amato, F., & Murgante, B. (2018): Population-based simulation of urban growth: The Italian case study. Sustainability, 10(12), 4838.

Dahmoune, B., & Mansour, H. (2018): Algerian northwestern seismic hazard evaluation based on the Markov model. Rudarsko-Geološko-Naftni Zbornik (The Mining-Geological-Petroleum Bulletin), 34(1). https://hrcak.srce.hr/ojs/index.php/rgn/article/view/7361

Engdahl, E. R., van der Hilst, R., & Buland, R. (1998): Global teleseismic earthquake relocation with improved travel times and procedures for depth determination. Bulletin of the Seismological Society of America, 88(3), 722–743.

Engdahl, E. R., Villasenor, A., DeShon, H. R., & Thurber, C. H. (2007): Teleseismic relocation and assessment of seismicity (1918–2005) in the region of the 2004 M w 9.0 Sumatra–Andaman and 2005 M w 8.6 Nias Island great earthquakes. Bulletin of the Seismological Society of America, 97(1A), S43–S61.

Fajarini, R., & Ratniarsih, I. (2019): The Application of Adaptive Concept Form of Tissue Culture Laboratory Building in Black Orchid Research and Development Center in Samarinda. IOP Conf. Ser.: Mater. Sci. Eng. 462(1), 012031.

Frankel, A. (1995): Mapping seismic hazard in the central and eastern United States. Seismological Research Letters, 66(4), 8–695.

Gardner, J., & Knopoff, L. (1974): Is the sequence of earthquakes in Southern California, with aftershocks removed, Poissonian? Bulletin of the Seismological Society of America, 64(5), 1363–1367.

GEM. (2020): The OpenQuake-engine User Manual. Global Earthquake Model (GEM) Open-Quake Manual for Engine version 3.8.1. 183. https://doi.org/10.13117/GEM.OPENQUAKE.MAN.ENGINE.3.8.1

Ghasemi, H., Cummins, P., Weatherill, G., McKee, C., Hazelwood, M., & Allen, T. (2020): Seismotectonic model and probabilistic seismic hazard assessment for Papua New Guinea. Bulletin of Earthquake Engineering, 18(15), 6571–6605.

Harmsen, S. (2007): USGS Software for Probabilistic Seismic Hazard Analysis (PSHA) Draft Document. Geological Survey, US (Http://Earthquake. Usgs. Gov/Research/Hazmaps/Product_data/2008/Software):

Hiemer, S., Woessner, J., Basili, R., Danciu, L., Giardini, D., & Wiemer, S. (2014): A smoothed stochastic earthquake rate model considering seismicity and fault moment release for Europe. Geophysical Journal International, 198(2), 1159–1172.

Ide, S., Takeo, M., & Yoshida, Y. (1996): Source process of the 1995 Kobe earthquake: Determination of spatio-temporal slip distribution by Bayesian modeling. Bulletin of the Seismological Society of America, 86(3), 547–566.

Irsyam, M., Cummins, P. R., Asrurifak, M., Faizal, L., Natawidjaja, D. H., Widiyantoro, S., Meilano, I., Triyoso, W., Rudiyanto, A., Hidayati, S., Ridwan, M., Hanifa, N. R., & Syahbana, A. J. (2020): Development of the 2017 national seismic hazard maps of Indonesia. Earthquake Spectra, 36(1_suppl), 112-136.

Irsyam, M., Munirwan, R. P., Yunita, H., & Usrina, M. Z. (2018): Geotechnical approach for occupational safety risk analysis of critical slope in open pit mining as implication for earthquake hazard. In IOP Conference Series: Materials Science and Engineering (Vol. 352, No. 1, p. 012035). IOP Publishing. The 7th AIC-ICMR on Sciences and Engineering 2017 18–20 October 2017, Banda Aceh, Indonesia

McClay, K., Dooley, T., Ferguson, A., & Poblet, J. (2000): Tectonic Evolution of the Sanga Sanga Block, Mahakam Delta, Kalimantan, Indonesia. AAPG Bulletin, 84(6), 765–786.

Metcalfe, I. (1996): Gondwanaland dispersion, Asian accretion and evolution of eastern Tethys. Australian Journal of Earth Sciences, 43(6), 605–623.

Moschetti, M. P., Mueller, C. S., Boyd, O. S., & Petersen, M. D. (2014): Development of an adaptively smoothed seismicity model for Alaska and implications for seismic hazard. In Tenth US national conference on earthquake engineering, Anchorage, Alaska (held on July 21-25, 2014)

Mulyoutami, E., Rismawan, R., & Joshi, L. (2009): Local knowledge and management of simpukng (forest gardens) among the Dayak people in East Kalimantan, Indonesia. Forest Ecology and Management, 257(10), 2054–2061.

Nasir, A., Lenhardt, W., Hintersberger, E., & Decker, K. (2013): Assessing the completeness of historical and instrumental earthquake data in Austria and the surrounding areas. Austrian Journal of Earth Sciences, 106(1), 90-102.

Nugraha, Andri D, Shiddiqi, H. A., Widiyantoro, S., Thurber, C. H., Pesicek, J. D., Zhang, H., Wiyono, S. H., Ramdhan, M., & Irsyam, M. (2018a): Hypocenter Relocation along the Sunda Arc in Indonesia, Using a 3D Seismic-Velocity Model. Seismological Research Letters, 89(2A), 603–612.

Nugraha, A. D., Supendi, P., Widiyantoro, S., Daryono, & Wiyono, S. (2018b): Earthquake swarm analysis around Bekancan area, North Sumatra, Indonesia using the BMKG network data: Time periods of February 29, 2015 to July 10, 2017. 1987(1), 020092.

Omang, A., Cummins, P., Robinson, D., & Hidayati, S. (2016). Sensitivity analysis for probabilistic seismic hazard analysis (PSHA) in the Aceh Fault Segment, Indonesia. Geohazards in Indonesia: Earth Science for Disaster Risk Reduction. https://doi.org/10.1144/SP441.5

Pagani, M., Monelli, D., Weatherill, G., Danciu, L., Crowley, H., Silva, V., Henshaw, P., Butler, L., Nastasi, M., & Panzeri, L. (2014): OpenQuake engine: An open hazard (and risk) software for the global earthquake model. Seismological Research Letters, 85(3), 692–702.

Parkinson, C. D., Miyazaki, K., Wakita, K., Barber, A., & Carswell, D. (1998): An overview and tectonic synthesis of the pre-Tertiary very-high-pressure metamorphic and associated rocks of Java, Sulawesi and Kalimantan, Indonesia. Island Arc, 7(1–2), 184–200.

Passarelli, L., Heryandoko, N., Cesca, S., Rivalta, E., Rohadi, S., Dahm, T., & Milkereit, C. (2018): Magmatic or not magmatic? The 2015–2016 seismic swarm at the long-dormant Jailolo volcano, West Halmahera, Indonesia. Frontiers in Earth Science, 6, 79.

Petersen, M. D., Mueller, C. S., Frankel, A. D., & Zeng, Y. (2008): Spatial seismicity rates and maximum magnitudes for background earthquakes (No. 2007-1437-J). US Geological Survey. https://doi.org/10.3133/ofr20071437J

Prayitno, G., Sari, N., Hasyim, A., & SW, N. W. (2020): Land-Use Prediction in Pandaan District Pasuruan Regency. International Journal of Geomate, 18(65), 64–71.

PusGen. (2017): *Peta Sumber dan Bahaya Gempa Indonesia Tahun 2017* [Map of the Source and Hazards of the Indonesian Earthquake in 2017] (1st ed.): Puslitbang Perumahan dan Pemukiman, Indonesia, 375p, ISBN 978-602-5489-01-3

Rashed, T., & Weeks, J. (2003): Assessing vulnerability to earthquake hazards through spatial multicriteria analysis of urban areas. International Journal of Geographical Information Science, 17(6), 547–576.

Satyana, A. H., Nugroho, D., & Surantoko, I. (1999): Tectonic controls on the hydrocarbon habitats of the Barito, Kutei, and Tarakan Basins, Eastern Kalimantan, Indonesia: Major dissimilarities in adjoining basins. Journal of Asian Earth Sciences, 17(1–2), 99–122.

Silva, V., Crowley, H., Pagani, M., Monelli, D., & Pinho, R. (2014): Development of the OpenQuake engine, the Global Earthquake Model's open-source software for seismic risk assessment. Natural Hazards, 72(3), 1409–1427.

Stirling, M. W., Verry, G. H. M., & Berryman, K. R. (2002). A new seismic hazard model for New Zealand. Bulletin of the Seismological Society of America, 92(5), 1878–1903.

Syahbana, A. J., Sari, A. M., Soebowo, E., Irsyam, M., Hendriyawan, H., & Asrurifak, M. (2019): The sensitivity of earthquake input motion correlation with arias intensity and amplification, case study: Yogyakarta Special Region. In Journal of Physics: Conference Series (Vol. 1280, No. 2, p. 022069). IOP Publishing (held in Bandung Indonesia, October 27, 2018).

Syahbana, A. J., Kurniawan, R., & Soebowo, E. (2018): Earthquake acceleration amplification based on single microtremor test. IOP Conference Series: Earth and Environmental Science, 118.

Syahbana, A. J., Goro, G. L., Saputra, O. F., Aditramulyadi, D. D., Irsyam, M., Asrurifak, M., & Hendriyawan, H. (2020): Application of Modified PSHA USGS Software in Java Island Bed Rock Peak Ground Acceleration and Hazard Curve with 2475 Years Return Period. International Journal of Advanced Science and Technology, 29(7), 3138–3148.

Taylor, M., & Thrift, N. (2012): The geography of multinationals: Studies in the spatial development and economic consequences of multinational corporations (Vol. 37): Routledge.

Trifunac, M., & Lee, V. (1992). A note on scaling peak acceleration, velocity and displacement of strong earthquake shaking by Modified Mercalli Intensity (MMI) and site soil and geologic conditions. Soil Dynamics and Earthquake Engineering, 11(2), 101–110.

Umar, Z., Pradhan, B., Ahmad, A., Jebur, M. N., & Tehrany, M. S. (2014): Earthquake induced landslide susceptibility mapping using an integrated ensemble frequency ratio and logistic regression models in West Sumatera Province, Indonesia. Catena, 118, 124–135.

Van De Weerd, A. A., & Armin, R. A. (1992): Origin and evolution of the Tertiary hydrocarbon-bearing basins in Kalimantan (Borneo), Indonesia. AAPG Bulletin, 76(11), 1778–1803.

Grünthal, G., & Wahlström, R. (2001). Sensitivity of parameters for probabilistic seismic hazard analysis using a logic tree approach. Journal of Earthquake Engineering, 5(03), 309-328.

Wakita, K., Miyazaki, K., Zulkarnain, I., Sopaheluwakan, J., & Sanyoto, P. (1998): Tectonic implications of new age data for the Meratus Complex of south Kalimantan, Indonesia. Island Arc, 7(1–2), 202–222.

Werner, M. J., Helmstetter, A., Jackson, D. D., Kagan, Y. Y., & Wiemer, S. (2010): Adaptively smoothed seismicity earthquake forecasts for Italy. Annals of Geophysics, 53(3), 107-116, 2010

White, L. T., Rawlinson, N., Lister, G. S., Waldhauser, F., Hejrani, B., Thompson, D. A., Tanner, D., Macpherson, C. G., Tkalčić, H., & Morgan, J. P. (2019): Earth's deepest earthquake swarms track fluid ascent beneath nascent arc volcanoes. Earth and Planetary Science Letters, 521, 25–36.

Woo, G. (1996): Kernel estimation methods for seismic hazard area source modeling. Bulletin of the Seismological Society of America, 86(2), 353–362.

Wu, C., Wei, Y. D., Huang, X., & Chen, B. (2017): Economic transition, spatial development and urban land-use efficiency in the Yangtze River Delta, China. Habitat International, 63, 67–78.

Yuliastuti, Y., Syaeful, H., Syahbana, A. J., Alhakim, E. E., & Sembiring, T. M. (2021). One dimensional seismic response analysis at the non-commercial nuclear reactor site, Serpong—Indonesia. Rudarsko-Geološko-Naftni Zbornik (The Mining-Geological-Petroleum Bulletin), 36(2), 1–10. https://doi.org/10.17794/rgn.2021.2.1

Zechar, J. D., Schorlemmer, D., Werner, M. J., Gerstenberger, M. C., Rhoades, D. A., & Jordan, T. H. (2013). Regional earthquake likelihood models I: First-order results. Bulletin of the Seismological Society of America, 103(2A), 787–798.

Zhao, D., Fujisawa, M., & Toyokuni, G. (2017): Tomography of the subducting Pacific slab and the 2015 Bonin deepest earthquake (Mw 7.9): Scientific Reports, 7(1), 1–8.

SAŽETAK

Izglađeni mrežni seizmički učinak primijenjen za uporabu zemljišta, studija slučaja na otoku Kalimantan, Indonezija

Izglađeni (filtriran) mrežni seizmički učinak temelji se na analizi seizmičnosti, tj. izračunu vrijednosti b i odgovarajuće magnitude. U studiji su prikupljeni i analizirani podatci pozadinskoga izvora, prikupljeni u PusGen katalogu koji obuhvaća približno 70 000 podataka. Korištena su dva programska paketa koja su ranije pouzdano upotrijebljena kod izradbe karte potresnih rizika Indonezije 2017. godine, odnosno njihovi dijelovi nazvani USGS PSHA i OpenQuake. Završni dio računa bila je usporedba karte ubrzanja s kartom uporabe zemljišta na otoku Kalimantan te analiza daljnjega održivog razvoja s obzirom na opasnosti i rizik potresa. Dobiveni su sljedeći rezultati: (1) sila ubrzanja s obzirom plitke potrese u prostoru Kalimantana mijenja se 0 – 0,25 g (prema USGS PSHA), odnosno 0 – 0,4 g (OpenQuake); (2) temeljem dubokih seizmičkih izvora najveće ubrzanje izračunano je u intervalu 0,15 – 0,25 g (USGS PSHA, OpenQuake); (3) uporaba zemljišta, kako danas, tako i u budućnosti, treba pratiti rezultate simulacija (ubrzanja), za koje je preporučeno da postanu dio urbanoga planiranja glavnoga grada regije, ali i okolnih prostora u kojima se rudari.

Ključne riječi:
izglađena mrežna seizmičnost, pozadinski izvori potresa, uporaba zemljišta, otok Kalimantan

Author’s contribution

Arifan J. Syahbana (1) (Ph.D. Student/Researcher, M.Eng, Geotechnics) provided the data processing and analysis of PSHA analysis and interpretation of the results. **Prahara Iqbal** (2) (Ph.D. Student/Researcher, MT, Geology) contributed with the geology of Kalimantan Island and its land-use. **Masyhur Irsyam** (3) (Professor, Civil Engineering/Geotechnics) participated in a critical review of the seismic analysis simulation and land-use correlation. **M Asrurifak** (4) (Lecturer/Researcher, Ph.D, Geotechnics) contributed with the catalogue data, and analyses using OpenQuake and USGS PSHA. **Hendriyawan H** (5) (Lecturer/Researcher, Ph.D., Offshore Engineering) provided the seismic analysis especially in processing declustering and completeness data.