JURNAL TEKNOSAINS

ISSN 2089-6131 (Print)
ISSN 2443-1311 (Online)
https://jurnal.ugm.ac.id/teknosains
https://doi.org/10.22146/teknosains.41483

VOLUME 9 No. 2, 22 Juni 2020 Halaman 91-180

MAPPING OF PGA VALUE USING PSHA METHOD IN WEST HALMAHERA NORTH MALUKU

***Rohima Wahyu Ningrum**
Department of Physics Education, Faculty of Teacher Training and Education
Universitas Khairun
Email: ima.geolive@gmail.com

Wiwit Suryanto
Department of Physics, Faculty of Mathematics and Natural Sciences
Universitas Gadjah Mada

Hendra Fauzi
Department of Architectural Engineering, Faculty of Engineering
Universitas Khairun

Estuning Tyas Wulan Mei
Department of Geography Development, Faculty of Geography

Submitted: 30-11-2018; Revised: 11-04-2019; Accepted: 16-04-2019

ABSTRAK

Gempa bumi di Halmahera Barat sangat merugikan warga dari segi struktural, walaupun korban jiwa manusia tidak terlalu signifikan. Tercatat pada kejadian gempa bumi tahun 2015, yakni 2.385 rumah warga rusak berat. Hal ini dikarenakan tingkat kerentanan dan infrastuktur daerah yang masih terbatas sehingga memiliki dampak gempa lebih besar dan akan mempengaruhi kestabilan serta kapasitas suatu daerah dalam hal pembangunan wilayah. Pemetaan daerah rawan bencana gempabumi dilakukan dengan metode probabilistic seismic hazard analysis (PSHA) untuk menganalisa parameter gerakan tanah yaitu percepatan tanah maksimum (PGA) sehingga dapat menentukan daerah rawan bencana gempabumi di daerah Halmahera Barat. Halmahera Barat termasuk dalam jalur subduksi dan sesar aktif, meliputi zona punggungan mayu (lempeng laut Maluku), zona gempa Sangihe dan zona gempa Halmahera-Irian. Input data yang dibutuhkan adalah data gempa daerah Halmahera Barat yang diperoleh dari beberapa katalog gempa, kemudian diolah dengan menggunakan bantuan software USGS-PSHA, Matlab, Z-Map, dan ArcGis. Hasil analisis seismic hazard yang diperoleh menunjukkan bahwa daerah Halmahera Barat merupakan wilayah yang relatif rawan terhadap bahaya gempa bumi karena masih sangat dipengaruhi oleh gempa subduksi dari lempeng Filipina, laut Maluku dan Sangihe. Ini ditunjukkan oleh nilai percepatan gempa di batuan dasar (Peak Ground Acceleration) untuk periode ulang 500 tahun sekitar 0,38 – 3,69 g dan 0,30 – 3,69 g untuk periode ulang 2500 tahun. Hasil pemetaan ini kemudian dibandingkan dengan peta SNI 03-1726-2012, diperoleh bahwa nilai PGA hampir mendekati kesesuaian yaitu 0,38 – 3,69 g dengan 0,3 – 2,0 g. Perbedaan kecil itu disebabkan oleh data gempa terkini yang terjadi dan mungkin belum digunakan pada peta SNI 03-1726-2012.

*Corresponding author: ima.geolive@gmail.com

Sehingga masih perlu dilakukan analisis lebih lanjut terutama kelengkapan data geologi daerah penelitian.

Kata Kunci: ***Halmahera Barat; PGA; PSHA.***

ABSTRACT

The earthquake in West Halmahera was very detrimental to residents in terms of structural even though the human casualties were not very significant. It was noted in the 2015 earthquake, which were 2,385 houses damaged. This happened due to the level of vulnerability and regional infrastructure is still limited so that it has a greater earthquake impact and will affect the stability and capacity of a region in terms of regional development. The mapping of earthquake-prone areas is carried out by probabilistic seismic hazard analysis (PSHA) method to analyze soil movement parameters, namely Peak Ground Acceleration (PGA) so that it can determine earthquake-prone areas in West Halmahera. West Halmahera is included in the subduction and active fault lines, including the Mayu ridge zone (Maluku plate), the Sangihe earthquake zone and the Halmahera-Irian earthquake zone. The input data needed is earthquake data in West Halmahera region obtained from several earthquake catalogs, then processed using the help of USGS-PSHA, Matlab, Z-Map, and ArcGIS software. The results of seismic hazard analysis indicate that the West Halmahera area is relatively vulnerable to earthquake hazards because it is still strongly influenced by megathrust earthquakes from the Philippine plate, Maluku plate, and Sangihe plate. This is showed by the value of the Peak Ground Acceleration for a 500 year return period of around 0.38 - 3.69 g and 0.30 - 3.69 g for the 2500 year return period. That outputs are then compared with the SNI 03-1726-2012 map, obtained that the PGA value is almost close to 0.38 - 3.69 g with 0.3 - 2.0 g. That little differences due to the latest earthquake data and may not be used on the SNI map 03-1726-2012. So that further analysis needs to be done, especially the completeness of the geological data of the study area.

Keywords: ***PGA; PSHA; West Halmahera.***

INTRODUCTION

Seismicity values in a region have a fairly close correlation with the level of seismic hazard. In general, information about Indonesia's tectonic order is quite good, especially for Western Indonesia, but further Central and East Indonesia still need to be done in order to obtain more accurate information.

West Halmahera is one of the areas in North Maluku with the highest level of earthquake vulnerability and unique. About 90% of all earthquakes that occur on earth are the result of tectonic events, especially movements in the fault area. The remaining 10% is related to volcanism, the collapse of underground cavities, or man-made consequences (Lowrie 2007). West Halmahera, which is the west coast area of Halmahera Island, which is included in the subduction and active fault lines, includes the Mayu ridge zone (Maluku plate), the Sangihe earthquake zone and the Halmahera-Irian earthquake zone. Halmahera arc in the east and Sangihe arc in the west are collided each other to cause earthquakes with a mechanism of shear and shear faults. Shallow earthquakes in the Maluku plate are associated with collisions of the Halmahera arc and other deformation processes. The crossbow collision forms the Maluku collision zone with unique and complex tectonics (Shiddiqi et al. 2015).

The scientific objective of this research is to compare seismic activity from one region to another so that it can be known the distribution of active earthquake zones or seismic activity. Maluku plate is formed by the presence of microplates, which are fragments of the main plates trapped between convergent plates (Widiwijayanti et al. 2004). The physiography of West Halmahera is marked by the existence of a volcanic alignment that extends from the city of Jailolo in the south to the town of Galela in the north, where the volcanoes of Dukono, Ibu, and Gamkonora are still active today (Sam Supriatna 1980). The active volcano in the Halmahera arc was produced due to subduction of the Northeast of Maluku (Hall and Wilson, 2000).

Halmahera has an active seismic activity along subduction plates with an earthquake depth of 200 km, depth of medium to shallow (< 50 km) seismic concentrated in the North-West and North-East islands (Passarelli, Heryandoko, Cesca, and Rivalta, 2018). Many earthquakes occur at the boundary of the plate which slowly moves and the energy from the strain that accumulates for years later suddenly slips and causes a lot of damage. Human helplessness in terms of understanding the earthquake hazard itself causes losses in any form, such as losses in the structural field, in the financial sector, even to death.

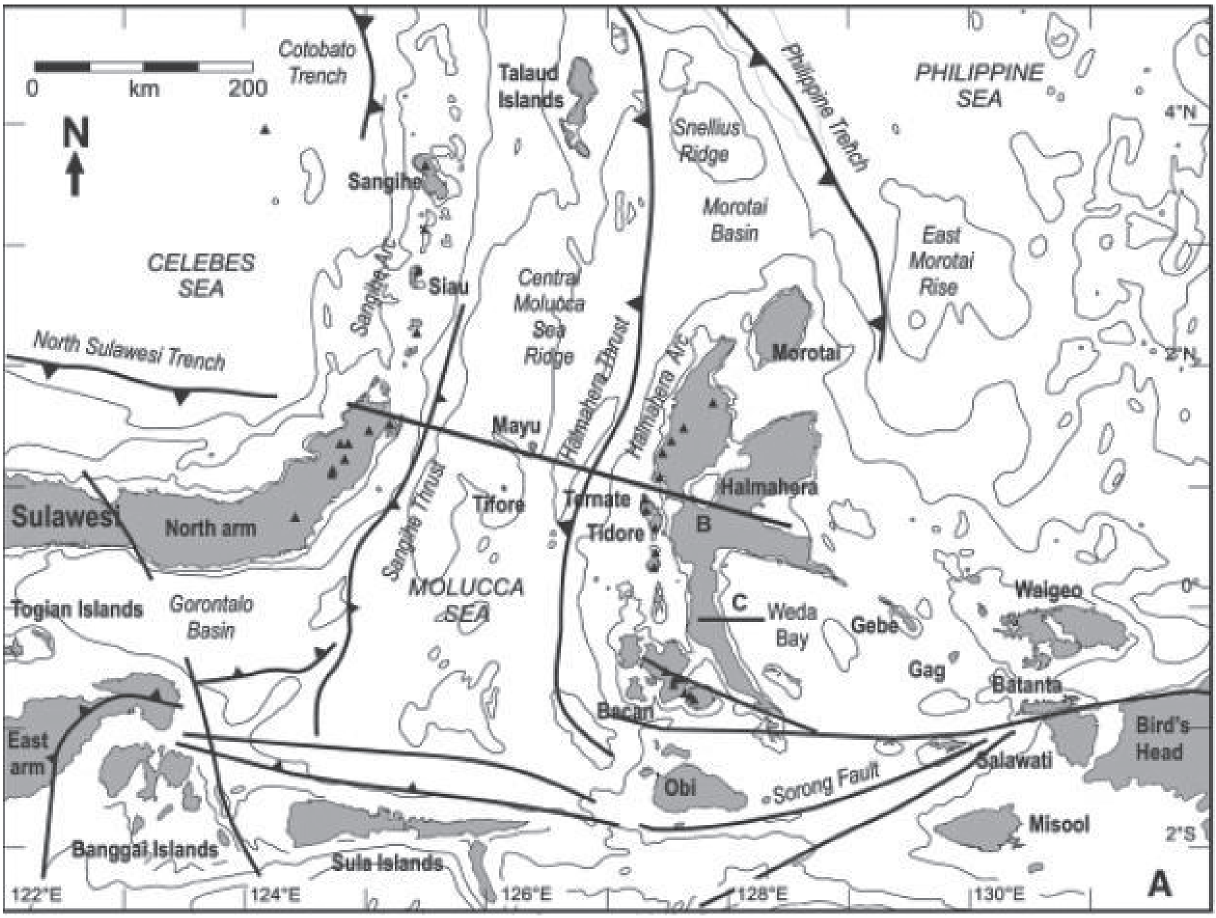


Figure 1
Tectonic Description of Halmahera and Its Surroundings
(Source: Waltham, Hall, Smyth, and Ebinger, 2008)

The earthquake that occurred in the West Halmahera region was very detrimental, even though the human casualties were not very significant. But it will affect the stability and capacity of a region in terms of regional development. There were recorded 2015 earthquakes, namely, 145 houses were severely damaged, 273 were moderately damaged, and 1.175 were slightly damaged (source: Badan Nasional Penanggulangan Bencana, 2016). So, from that, it is necessary to study the mapping of earthquake-prone areas.

Seismic hazard analysis is an analysis that describes the dangerous potential of a natural phenomenon related to earthquakes such as soil shock, fault rupture, and soil liquefaction. The results of seismic hazard analysis can be used in making macrozonation and microzonation maps for earthquake mitigation planning and recommendations for detailed plans for regional spatial planning. Then a seismic hazard risk analysis is also needed to assess the possibility of losses (human, social, economic) related to seismic hazards.

The amplitude parameter that is often used to explain the characteristics of ground motion is maximum ground acceleration (PGA). Maximum ground acceleration depends on earthquake history data, type of earthquake, earthquake magnitude, distance to the epicenter, and local soil structure and type. The value generated from maximum land acceleration can indicate a seismic hazard, which is calculated for earthquake disaster mitigation and the design of earthquake-resistant building spatial structures in a region.

The mapping of earthquake-prone areas is carried out by a Probabilistic Seismic Hazard Analysis (PSHA) method to analyze soil movement parameters, namely Peak Ground Acceleration (PGA) so that it can determine earthquake-prone areas in West Halmahera. Mapping the level of potential earthquake risk based on a map of PGA can also provide recommendations in the placement of residential buildings and other vital buildings (Brotopuspito, Prasetya, and Widigdo, 2006). The PSHA method uses the assistance of the 2007 USGS PSHA program developed by Stephen Harmsen in 2007.

The process of calculating the PSHA method was developed by (Merz and Corner, 1973) and is still used today, but the analysis model and calculation techniques are still being developed by the EERI Committee on Seismic Risk (EERI Committee on Seismic Risk 1989). The stages of the PSHA model and concept developed by EERI, namely a) identification of earthquake sources, b) earthquake source characterization, c) selection of attenuation functions, and d) calculation of earthquake hazard. In this calculation the general form of total probability theory is used, can be expressed in the equation as follows:

$$P\,[I \geq i] = \int_r \int_m P[I \geq i \mid m \text{ dan } r]\, f_M(m)\, F_R(r)\, dr\, dm$$

with:

f_M = the magnitude of the density function

f_R = density function of hypocenter distance

$P[I \geq i \mid m \text{ dan } r]$ = random probability conditions with the intensity I which exceeds the value of *i* at *a* site m due to the earthquake magnitude and hypocenter distance *r*.

Earthquakes are natural phenomena that are random in nature that cannot be determined with certainty, both the size, location and time of occurrence. The risk of seismic hazard can be presented by the value of risk. With the concept of probability, an earthquake with a certain intensity and return period can be estimated. This probability value reflects earthquake risk.

Seismic risk analysis using probabilistic methods requires parameters *a-b* value, to determine the frequency of earthquake vents according to Gutenberg-Richter (G-R). The parameters used to determine earthquake characteristics are *a-b* value, maximum magnitude, attenuation function, and logic tree. Seismic parameters *a-b* value is seismic parameters for analyzing earthquake risk. Describing the frequency or number of earthquake events from an earthquake source that occurs in bedrock in an area during a certain interval. Using probabilistic methods, having the following relationships:

$$\text{Log } N(m) = a - bm$$

with,

N (*m*) = annual incidence of an earthquake with a magnitude greater than or equal to *m* in a particular area.

a and b value = constants that describe each activity and the slope or in other words, the parameter b, or b-value which describes the ratio of small to large earthquakes.

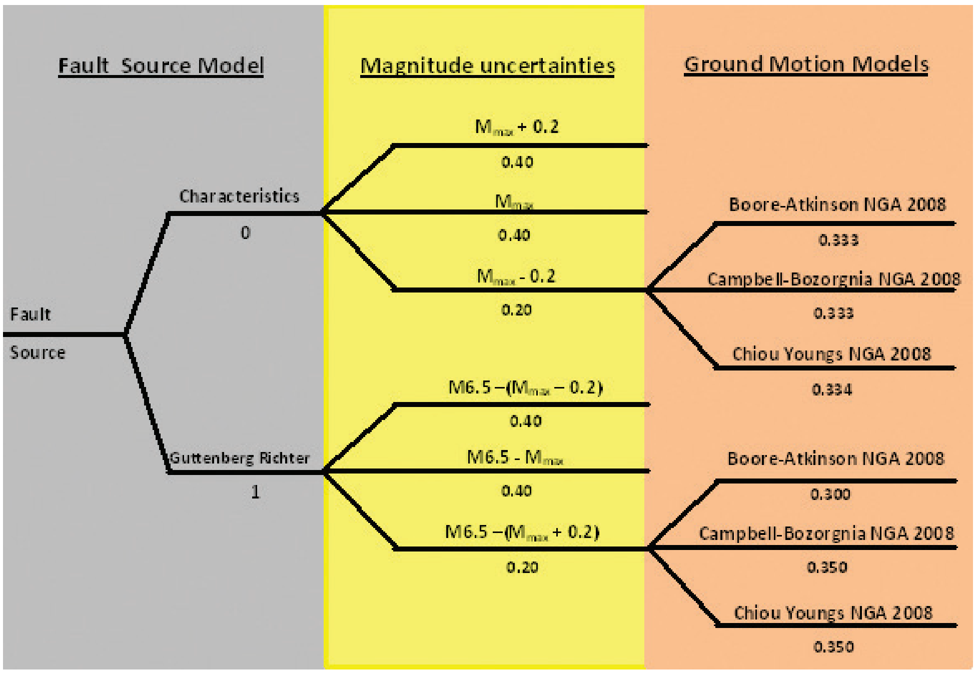
N (m) states the intensity of an earthquake with a magnitude greater a certain period of time. The greater the b value, the greater the number of large earthquake events. Because this b value is very decisive in earthquake hazard analysis, many studies have examined methods to obtain this value.

The earthquake source mechanism used in this analysis is divided into three parts, namely: earthquake source for fault transform zone, earthquake source for subduction zone, and background source for gridded seismicity. The attenuation equation used for seismic source models (Irsyam, Asrurifak, Budiono, Triyoso, and Firmanti, 2010).

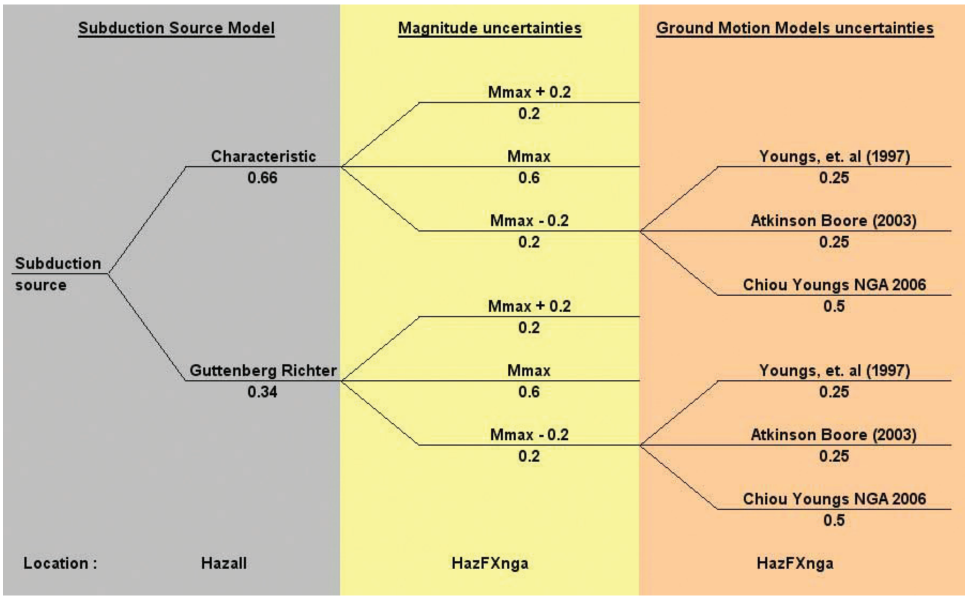
Attenuation function for shallow crustal earthquake source, for fault and shallow background earthquake source models, use Boore-Atkinson NGA equation, Campbell-Bozorgnia NGA equation, and Chiou-Youngs NGA equation. Attenuation function for subduction interface (Megathrust) earthquake source is Geomatrix subduction equation, Atkinson-Boore BC rock and global source subduction equation, and Zhao, with variable Vs30 equation. And attenuation function for Benioff (deep intraslab) background earthquake source is intraslab seismicity Cascadia region-rock condition equation, Geomatrix slab seismicity rock equation, and intraslab seismicity worldwide data region-rock condition equation.

Making attenuation functions is based on recording earthquake signal data from other regions with similar geological characteristics and seismotectonic conditions to the studied area because of the unavailable data. Maximum acceleration on the surface is influenced by soil conditions such as type/thickness and thickness of the layer. The effect of the magnitude of the change in the acceleration value from bedrock to the surface of the soil is referred to as the soil amplification factor. The travel of seismic waves from bedrock to the surface of the land is influenced by local soil conditions, in this case, the local conditions have an influence in the potential for damage that can increase the magnitude of the earthquake acceleration from the bedrock to the soil. Judging from the many previous earthquake events that were caused by local conditions, which were supposed to have an earthquake that was not too large but the results were very damaged. From here we can find out that a review of the local conditions in the analysis is very important so that the results will be used for the design of earthquake resistant structures (Ningrum 2011).

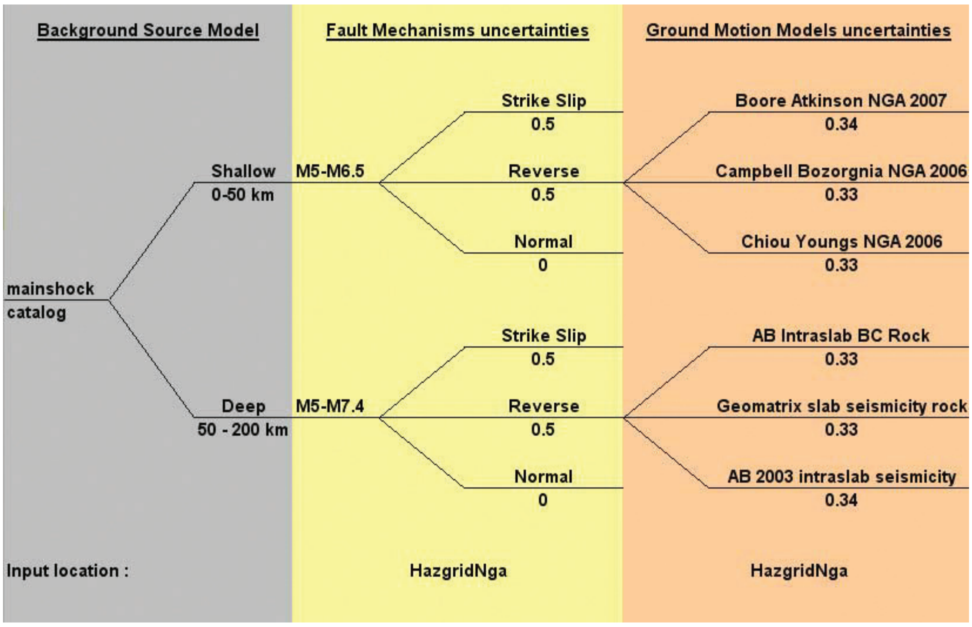
The use of the logic tree in PSHA is very necessary due to the uncertainty factor in managing data for analysis of seismic hazard. With this treatment model, the data, earthquake source parameters, and attenuation models used can be accommodated with weights according to uncertainty (Irsyam et al. 2010).



(a)



(b)



(c)

Figure 2
(a) Logic Tree Model for The Fault Seismic Source,
(b) Logic Tree Model for The Subduction Seismic Source (Megathrust), and
(c) Logic Tree Model for The Background Seismic Source
(Source: Software USGS-PSHA 2007)

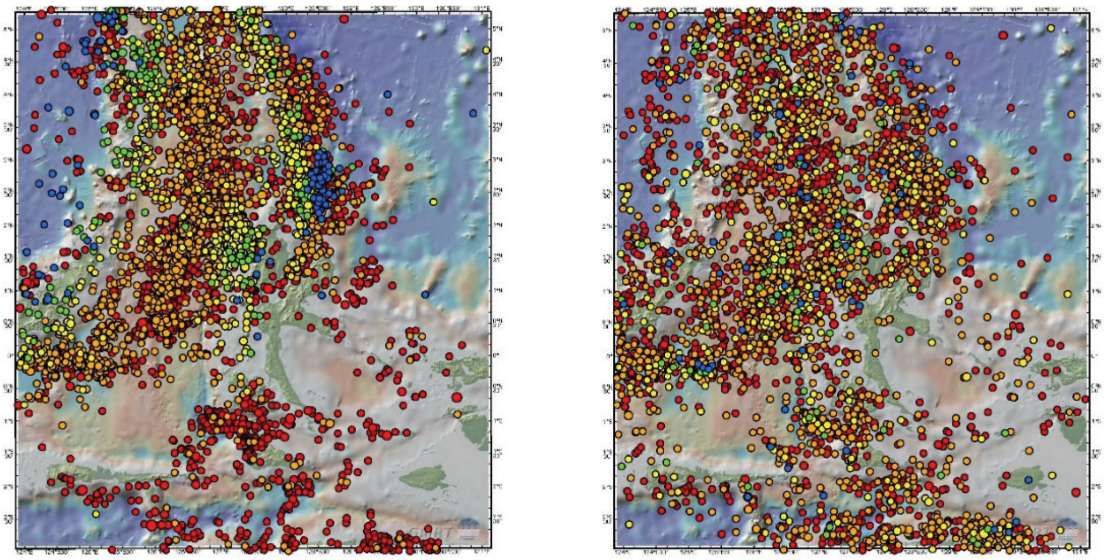
METHOD

This study uses the Probability Seismic Hazard Analysis method. The PSHA method was developed by McGuire and is one method used to determine the level of seismic risk based on the earthquake source model. An earthquake source model is needed as a relationship between earthquake event data and for annual rate data are used from 1910-2017. The earthquake catalog used is:

1. National Earthquake Information Center U.S. Geological survey (NEICUSGS) where this data is a combined data of earthquake catalogs from USGS,
2. International Seismological Summaries (ISS),
3. International Seismological Center (ISC),
4. Preliminary Determination of Epicenter (PDE),
5. The Advanced National Seismic System (ANSS) composite catalog from worldwide earthquake catalog where medium to large earthquakes have been relocated and corrected.

The separation of main or independent earthquakes (main shock) is used to eliminate the foreshock and aftershock earthquakes through the approach of empiric (Gardner and Knopoff 1974) with the help of the Z-Map program. The results of separation from the foreshock and aftershock earthquakes are shown in Figure 3.

From the earthquake hypocenter distribution map, it shows that for large earthquakes most occur in the Sangihe Plate. Areas with a dominant hypocenter distribution of moderate earthquakes are around the Molluca and Halmahera Island while the hypocenter distribution of small earthquakes is found throughout the North Maluku region from north to south. The moderate and large earthquakes are affected by the Maluku, Sangihe and Philippine sea plates while the small is partly due to the activity of the Sula fault, Sorong fault and other minor faults that have not been identified.



(a) (b)

Legend:

SEISMICITY						
● *Shallow* (0-50 km)	● *Deep* 1 (50-100 km)	● *Deep* 2 (100-150 km)	● *Deep* 3 (150-200 km)	● *Deep* 3 (200-300 km)		
o M 2	o M 3	o M 4	o M 5	M 6	M 7	M 8

Figure 3
(a) Map of Main Earthquake Distribution Before Separation for The Combined Catalog BMKG, USGS, ISS, ISC, PDE, And ANSS
(b) Map of The Main Earthquake Distribution After Separation Based on Gardner & Knopoff (1974) Criteria

Data Processing and Analysis

Data processing to produce PGA values using the Z-Map program and the USGS-PSHA 2007. The earthquake data obtained from the earthquake catalog then carried out the data processing stages, are shown in Figure 4.

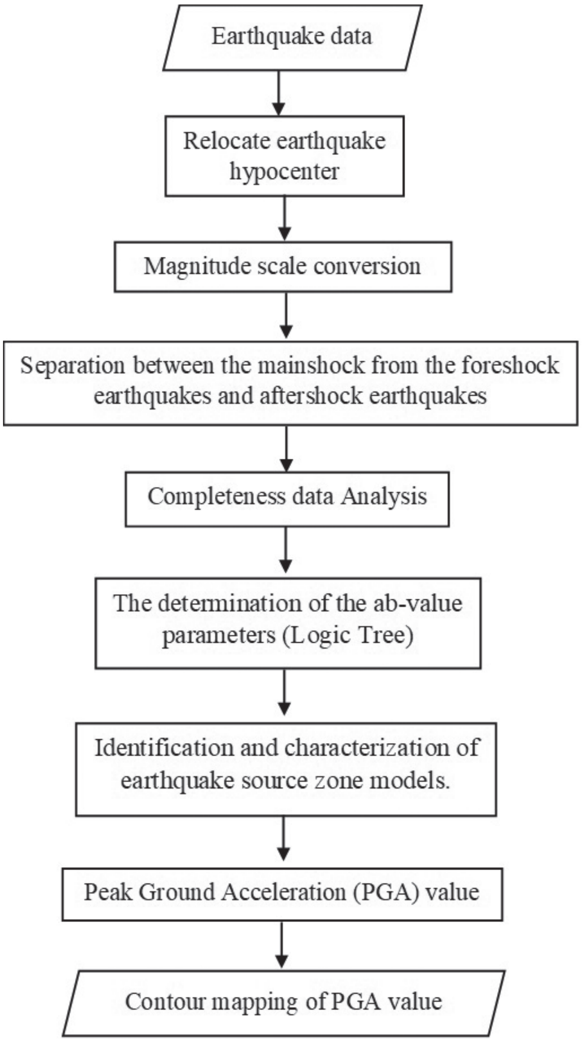


Figure 4
Flow Chart Data Processing Stages
(Source: Ningrum et al. 2018)

The results of contour mapping of PGA values carried out with the help of program hazard USGS-PSHA 2007 were the peak ground acceleration (PGA) values in the period T = 0 seconds, T = 0.2 seconds and T = 1 seconds for probabilities exceeding 10% and 2% in 50 years.

RESULTS AND DISCUSSION

Map of *Hazard* PSHA

The results of data analysis carried out with the help of the USGS-PSHA 2007 program hazard were in the form of a peak acceleration map (SB) map on peak ground acceleration (PGA) conditions or in the period T = 0 seconds and the response spectrum acceleration map in the period T = 0.2 seconds and T = 1 second for probabilities exceeding 10% and 2% in 50 years.

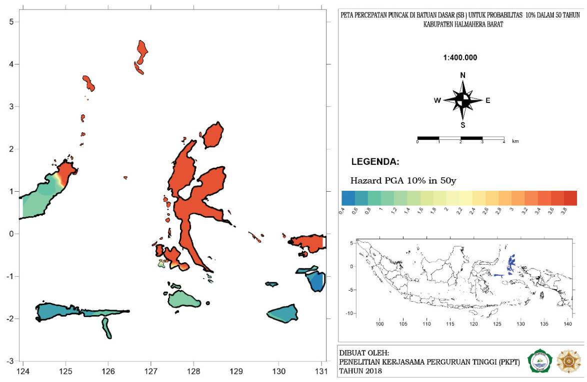


Figure 5
Map of The Peak Acceleration of Bedrock (SB) for A Probability Exceeding 10% in 50 Years.
(Source: Ningrum et al. 2018).

The peak acceleration map in the bedrock of North Maluku region based on three earthquake source models for 10% probability in 50 years is shown in Figure 6. From the map image, it can be seen that the West Halmahera region has an acceleration value earthquakes are quite high, this is influenced by the subduction earthquake (megathrust) source from the Philippine plate, Maluku plate, and Sangihe plate and fault earthquake source. It is seen that the West Halmahera area is dominated by hazard values 3.8 g with probabilities exceeding 10% in 50 years.

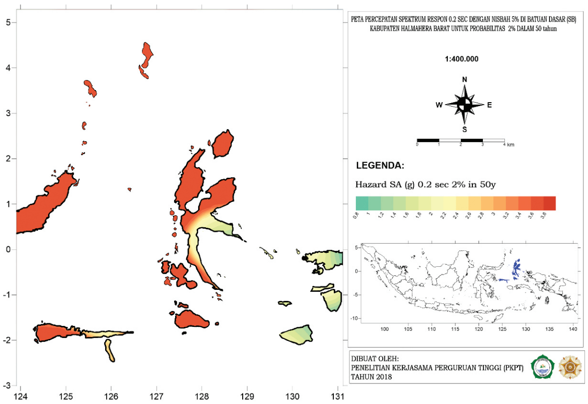


Figure 6
Map of Acceleration at Response Spectrum 0.2 Sec with Attenuation Ratio 5% of Bedrock (SB) for A Probability Exceeding 2% in 50 Years (Source: Ningrum et al., 2018)

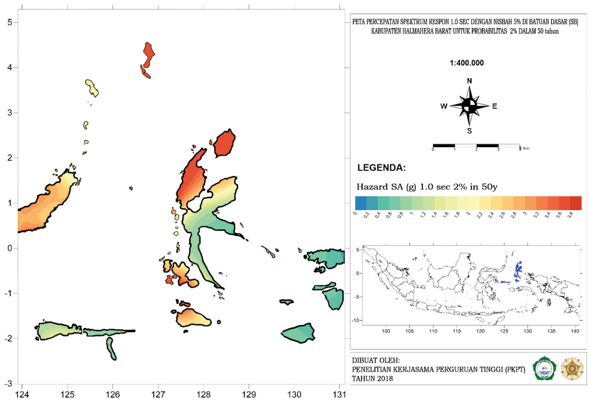


Figure 7
Map of Acceleration at Response Spectrum 1.0 Sec with Attenuation Ratio 5% of Bedrock (SB) for A Probability Exceeding 2% in 50 Years (Source: Ningrum et al., 2018)

The acceleration value in the 0.2 second spectrum response in the West Halmahera area (Figure 8) is still dominated by 3.8 g with a probability of 2% in 50 years. The PGA value in the subduction zone will be greater than the area far from the subduction zone. It can be concluded that the pattern of inter-plate subduction located around the study area plays an important role in the occurrence of earthquakes that have enormous power, although previously only earthquake-magnitude earthquake that small. Hazard maps as a result of subduction seismic sources provide significant value in areas close to the source until a considerable distance though, another case with the model due to the fault seismic source. the fault seismic source also gives significant value to the area near-fault seismic source. Value changes that occur quite dramatically and the effect on the close proximity to the fault seismic source compared to the distance that the farther the fault seismic source.

Hazard values for West Halmahera at probabilities exceeding 2% in 50 years at response spectrum 1.0 sec its shows in Figure 7 have a value of 0.4 - 3.8 g. Earthquake source models that have been clearly known it's seismotectonic model will be seen its value of the dominant hazard around the seismic source. Compared with the seismic source model that has not been clearly known it's a seismotectonic model so it will be much controlled by background seismic source model.

Comparison with The Earthquake Hazard Map of SNI 03-1726-2012

PSHA seismic hazard maps at peak acceleration in bedrock for the exceeded probability of 10% in 50 years will be compared with Indonesia 2017 source and earthquake hazard maps issued by the National Earthquake Study Center (PUSGEN) and the Ministry of Public Works and Public Housing in 2017.

Overall it is known that the results of the comparison of the earthquake acceleration values in bedrock for a probability exceeding 10% in 50 years in West Halmahera obtained with hazard values from the results of 2017 PUSGEN are almost close to suitability i.e. 0.2 – 0.8. The difference in value is because in this study using the latest earthquake data that occurred that PUSGEN might not have used. And in processing the data there must be trial and error that makes the value of processing results differ in the scale of numbers behind Coma. In addition, the parameter data used is the result of the calculation of the latest microtremor data in the study area.

CONCLUSION

The results of seismic hazard analysis show that the West Halmahera area is an area that is relatively prone to earthquake hazards because it is still strongly influenced by subduction (megathrust) earthquakes from the Philippine plate, Maluku plate, and Sangihe plate. This is indicated by the peak ground acceleration (PGA) for a 500 year return period of around 0.38 - 3.69 g and 0.30 - 3.69 g for the 2500 year return period.

This research was conducted as a form of earthquake disaster mitigation efforts and is expected to minimize human fatalities, infrastructure losses, environmental damage and the psychological impact of the West Halmahera area. The problem faced in this study is on fault data that is suspected of being active in the West Halmahera area, however, the characteristics and parameters are unknown. Based on Shiddiqi et al. (2015) that it is necessary to do further studies to obtain data and parameters specifically the geology for the West Halmahera region.

BIBLIOGRAPHY

Badan Nasional Penanggulangan Bencana. 2016. *Data Bencana Indonesia Tahun 2015*. Jakarta: BNPB.

Brotopuspito, Kirbani Sri, Tiar Prasetya, and Ferry Markus Widigdo. 2006. “Percepatan Getaran Tanah Maksimum Daerah Istimewa Yogyakarta 1943-2006.” *Jurnal Geofisika*, 7(1): 19–22.

EERI Committee on Seismic Risk. 1989. “The Basics of Seismic Risk Analysis.” In *Earthquake Spectra*, 675–702.

Gardner, J.K., and L Knopoff. 1974. “Is The Sequence Of Earthquakes In Southern CALIFORNIA, With Aftershocks Removed, Poissonian?” *Bulletin of the Seismological Society of America*, 64(5): 1363–67.

Hall, R., and M. E.J. Wilson. 2000. “Neogene Sutures in Eastern Indonesia.” *Journal of Asian Earth Sciences*, 18: 781–808.

Irsyam, Masyhur, Asrurifak, M, Hendriyawan, Budiono, Bambang, Triyoso, Wahyu, and Firmanti, Anita. 2010. “Development of Spectral Hazard Maps for a Proposed Revision of the Indonesian Seismic Building Code.” *Geomechanics and Geoengineering*, 5(1): 35–47.

Lowrie, William. 2007. Eos, Transactions American Geophysical Union *Fundamentals of Geophysics*. New York: Cambridge University Press.

Merz, Hans Arnold, and C Allin Corner. 1973. “Aftershock in Engineering Seismic Risk Analysis.” *Report R73-25. Massachusetts: Departement of Civil Engineering, MIT*.

Ningrum, Rohima Wahyu. 2011. “Analisis Probabilitas Seismic Hazard Untuk Daerah Kepulauan Maluku.” Tesis. Universitas Gadjah Mada.

Ningrum, Rohima Wahyu, Hendra Fauzi, Wiwit Suryanto, and Estuning Tyas Wulan Mei. 2018. *Mikrozonasi Seismic Hazard Daerah Hakmahera Barat, Provinsi Maluku Utara*. Laporan Penelitian,Ternate.

Passarelli, Luigi, Nova Heryandoko, Simone Cesca, and Eleonora Rivalta. 2018. “Magmatic or Not Magmatic ? The 2015 – 2016 Seismic Swarm at the Long-Dormant Jailolo Volcano , West.” *Frontiers in Earth Science*, 6(June): 1–17.

Sam Supriatna. 1980. “Peta Geologi Lembar Morotai, Maluku Utara 1:250,000 [Indonesia] = Geologic Map of the Morotai Quadrangle, North Maluku 1:250,000 [Indonesia] (Map, 1980) [WorldCat.Org].” *Bandung, Indonesia : Pusat Penelitian dan Pengembangan Geologi, 1980.*: 2517, 2617, 2618. https://www.worldcat.org/title/peta-geologi-lembar-morotai-maluku-utara-1250000-indonesia-geologic-map-of-the-morotai-quadrangle-north-maluku-1250000-indonesia/oclc/38901163 (January 4, 2019).

Shiddiqi, Hasbi Ash, Widiyantoro, Sri, Nugraha, Andri Dian, Ramadhan, Mohammad, Wandono, Sutiyono, Handayani, Titi, and Nugroho, Hendro. 2015. "Preliminary Result of Teleseismic Double-Difference Relocation of Earthquakes in the Molucca Collision Zone with a 3D Velocity Model." In *AIP Conference Proceedings*,.

Waltham, Dave, Robert Hall, Helen R. Smyth, and Cynthia J. Ebinger. 2008. "Basin Formation by Volcanic Arc Loading." In *Special Paper 436: Formation and Applications of the Sedimentary Record in Arc Collision Zones*,.

Widiwijayanti, Christina, Tiberi, Christel, Deplus, Christine, Diament, Michel, Mikhailov, Valentin and Louat, Remy. 2004. "Geodynamic Evolution of the Northern Molucca Sea Area (Eastern Indonesia) Constrained by 3-D Gravity Field Inversion." *Tectonophysics*, 386: 203–22.