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Sensitivity Analysis of Correlation Distance (R) Parameter Value to PGA Value by Using PSHA Method

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ABSTRACT Indonesia is one of the countries prone to earthquakes due to its geographical condition, which is located at the confluence of three main tectonic plates: the Indo-Australian Plate, the Eurasian Plate, and the Pacific Plate. In the context of earthquakes, the terms correlation distance and PGA (*Peak Ground Acceleration*) are known. Problems in correlation distance (R) only exist in background source earthquakes because of the *Smoothed Gridded Seismicity* process. PGA is a measure of the maximum ground acceleration that occurs during an earthquake. PGA is used in earthquake engineering to assess the potential damage that may be caused by an earthquake. Therefore, it is necessary to conduct research to determine the effects of the correlation distance parameter (R) on the PGA value using USGS PSHA software. The data used in this study are *background earthquake* data obtained from the National Earthquake Center Catalog (PuSGeN) in 2017. The research locations include Banten, Lampung, Southeast Sulawesi, West Sumatra, Gorontalo, and Bali. These locations were chosen because of their geographical conditions which are located near or around tectonic plates, making them prone to earthquakes. This research utilizes several modules from the USGS PSHA, namely AgridMLsm, HazgridXnga2, and HazallXL to process *background earthquake* data using ArcMap software from ArcGIS. The correlation distance (R) used in this study is 25, 50, 75, and 100 km. From the six provinces used as research locations, it is concluded that the difference in distance affects the resulting PGA values. In general, the greater the correlation distance value, the greater the PGA value. However, there are some points where the smaller the correlation distance, the larger the PGA value because these points are close to many earthquake sources.

KEY WORDS Earthquake; Correlation Distance; PGA; USGS PSHA; Earthquake Source

1. INTRODUCTION

Indonesia is an earthquake-prone country because Indonesia is located at the confluence of three major tectonic plates, namely the Indo-Australian Plate, Eurasian Plate, and Pacific Plate. The movement and collision between these plates often produce earthquakes (McNamara et al., 2019; Thompson et al., 2019). Earthquakes are vibrations or shocks that occur on the earth's surface due to the sudden release of energy in the earth's crust (Riyanti & Rasimeng, 2020; Triyoso et al., 2020). In Indonesia, there have been many large earthquakes which have terrible consequences, including the Aceh earthquake and tsunami (2004), the Yogyakarta earthquake (2006), the West Sumatra earthquake (2009), the Palu earthquake and tsunami (2018), and so on. Based on its source in *Seismic Hazard Analysis*, earthquakes are divided into three types, namely *Megathrust, Fault*, and Background (Riyanti & Rasimeng, 2020; Rohadi et al., 2015). *Background earthquakes* are a type of earthquake produced by seismic activity that occurs beneath the earth's surface, but is not associated with a clear subduction zone or fault. *Background earthquakes* are divided into two categories: *Shallow Background* (earthquake sources up to 50 km) and *Deep Background* (earthquake sources 50 km - 300 km) (Asrurifak et al., 2009; Wiens, 2001).

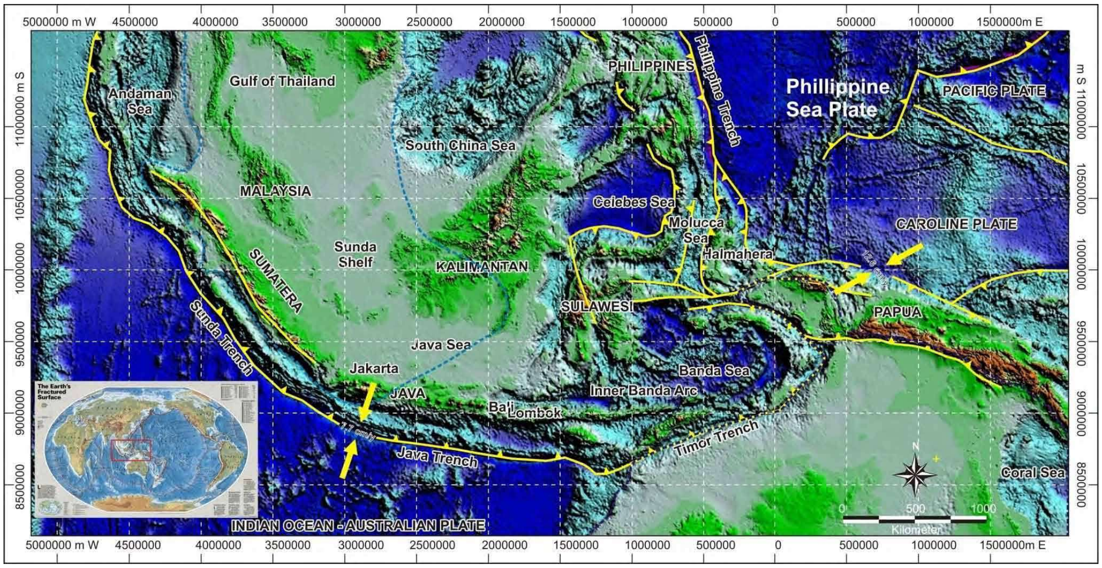

Figure 1 Tectonic elements of Indonesia and the movement of tectonic plates (Hamilton, 1979)

This study uses data from several locations as sources of research data, namely Banten, Lampung, Southeast Sulawesi, West Sumatra, Gorontalo and Bali. Banten, Lampung and West Sumatra were chosen because they are located in the Sunda subduction zone where the Indo-Australian Plate is underneath the Eurasian Plate, making them highly vulnerable to earthquakes. Southeast Sulawesi was chosen because it is located between two large tectonic plates, the Eurasian Plate and the Pacific Plate. Bali was chosen because it is located along the Bali Fault, which is the boundary between the Indo-Australian Plate and the Sunda Plate. Gorontalo is located in the northern part of Sulawesi Island, between two major tectonic plates, the Sunda Plate and the Philippine Plate and adjacent to the Australian Plate. The tectonic conditions in each region have caused several major earthquakes in these areas. Thus, it is necessary to conduct a PSHA or *Probabilistic Seismic Hazard Analysis* which is a scientific method used to understand seismic hazards in an area with a probabilistic approach to reduce the risk due to earthquakes (Gerstenberger et al., 2020; Puteri et al., 2019). In Indonesia, this method has been used to map earthquake hazards in areas such as Lampung and Bali, and the analysis results are used to determine the level of earthquake hazard and develop disaster mitigation strategies (Oktaviani et al., 2020; 2023; Puteri et al., 2019; Putu, 2020).

The parameter R is related to the distance between the epicenter and the observation location (Mousavi & Beroza, 2019; Pasau & Tanauma, 2011). The value of R or the correlation distance at the Background source earthquake is used to account for the influence of earthquakes around the analyzed location. In this case, the correlation distances used are 25 km, 50 km, 75 km, and 100 km, each of which represents a certain distance from the *Background earthquake* source to the site under review (Pasau & Tanauma, 2011; Triyoso et al., 2020). In this study, it will be seen how the influence of Parameter R (distance to the earthquake source) using the USGS PSHA (*Probabilistic Seismic Hazard Analysis*) software on the value of PGA or *Peak Ground Acceleration*. PGA is a measure of the maximum ground acceleration that occurs during an earthquake. PGA is used in earthquake engineering to assess the potential damage that may be caused by an earthquake. Therefore, this research is important to be carried out as a form of earthquake disaster mitigation. The purpose of this research is to determine the level of sensitivity of correlation distance (R) to PGA value from *Background earthquake*.

2. METHODS

2.1 Earthquake Data

In order to do a sensitivity analysis of the R value to the PGA value, the first step was to collect previous earthquake data. The earthquake data was sourced from the 2017 National Earthquake Center Catalog (PuSGeN). Thereafter, mapping was carried out using ArcMap software from ArcGIS and produced an earthquake distribution map as shown in Figure 2.

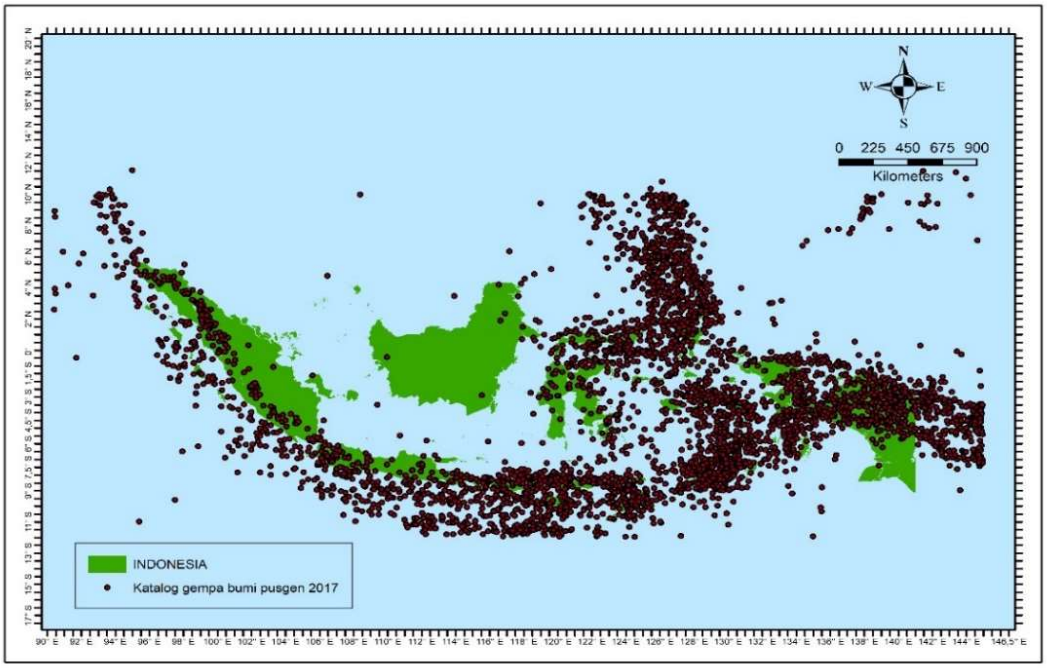

Figure 2 Map of earthquake distribution in Indonesia from the National Earthquake Center Catalog (PuSGeN, 2017)

2.2 Methodology

From the past earthquake distribution, locations which are earthquake-prone in Indonesia can be determined. The identified areas are Banten, Lampung, Southeast Sulawesi, West Sumatra, Gorontalo and Bali. Four correlation distances (R) are used in the research : 25 km, 50 km, 75 km, and 100 km. Then, the data was processed using USGS PSHA software.

USGS PSHA consists of several modules designed to process various earthquake source mechanisms. The filtrate and hazFXnga7c modules process data from Fault Earthquake sources. While the AgridMLsm and HazgridXnga2 modules process data from *Background earthquake* sources (Ginting et al., 2020; Oktaviani et al., 2023). The HazSUBXnga module handles data from *Megathrust Earthquake sources*. After all the data is processed, the HazallXL module is used to combine and display the results of each type of earthquake source. Since the data used in this study is only of *Background earthquake* data, the modules used are AgridMLsm, HazgridXnga2, and HazallXL (Ginting et al., 2020; Oktaviani et al., 2023).

Background earthquake source analysis is carried out by providing input in the form of boundaries, distance, distance between points, year data, minimum magnitude, and earthquake source files which will then be processed with the AgridMLsm module. AgridMLsm functions to process seismic data related to *background earthquakes*. This module collects and analyzes seismic data from various sources to identify *Background earthquakes*, as well as determine the distribution of earthquake magnitudes in an area which in this research is used in the Banten, Lampung, Southeast Sulawesi, West Sumatra, Gorontalo and Bali regions. Using a *grid* approach, AgridMLsm models *background earthquake* sources and calculates seismic activity in each part of the *grid*, providing a more detailed picture of the seismic risk in the region in question. The results from AgridMLsm are then used as input in a probabilistic seismic hazard analysis (PSHA), helping to estimate the potential maximum ground acceleration (PGA) and spectral acceleration (SA) that could be generated by a *background earthquake*. (Aprillianto et al., 2016; Andrianto et al., 2023).

The results of the processing are in a file, which will be processed again with the HazgridXnga2 module which produces output in the form of binary code. HazgridXnga2 serves to process the results of the *background earthquake* data processing that has been generated by the AgridMLsm module. This module takes the output file from AgridMLsm and converts it into binary code. This process serves to ensure that the *background earthquake* data can be used in subsequent analysis steps. HazgridXnga2 processes the seismic data further, producing output that is more structured and ready to be processed by the next module. (Aprillianto et al., 2016; Andrianto et al., 2023).

The binary code files can then be directly processed using the HazallXL module (Syahbana et al., 2020; Oktaviani et al., 2023). This module takes the binary code generated by HazgridXnga2 and converts it into a file with a more readable format, such as *.txt. This file can then be exported to *.csv format to facilitate visualization and further analysis using ArcMap software. Then, after obtaining the visualization results from ArcMap for each of the correlation distance determined for the selected areas, ten points were selected for each area.

To iterate, the data processing process in this study begins by entering the coordinate points of several locations and the correlation distance (R) determined in the study in AgridMLsm and HazgridXnga2 in *.txt format based on the 2017 National Earthquake Center Catalog (PuSGeN) data. Then, the step that must be taken is to process the data using a *Command Prompt* which will produce a *.csv format of the data used with the help of AgridMLsm, HazgridXnga2, and HazallXL software. The data in *.csv format will be processed using ArcMap software from ArcGIS, which will produce points on the map at the specified location.

Ten points in each region are then randomly selected. Once selected, the points will be searched for SA values based on their *longitude* and *latitude* in the *.csv file generated after processing by the HazallXL module. Then, to be able to see the comparison of each region and the correlation distance, the results will be formed into a graph. After obtaining the results in the form of a graph, a comparison is made to determine whether or not there is an influence of the value of the correlation distance parameter (R) on the PGA value.

3. RESULTS

The results of the sensitivity analysis of correlation distance parameters (R) in Banten, Lampung, Southeast Sulawesi, West Sumatra, Gorontalo and Bali provinces are shown in this section. In the PSHA analysis of the Banten area *background earthquake* source with correlation distance of (A) 25 km, (B) 50 km, (C) 75 km, and (D) 100 km are shown in figure 3A-D. Figure 3A has a PGA value in the range of 0.20-0.60 g. Figure 3B has a PGA value with a range of 0.25-0.60 g. Figure 3C has PGA values with a range of 0.30-0.50 g. Figure 3D has PGA values with a range of 0.30-0.50 g.

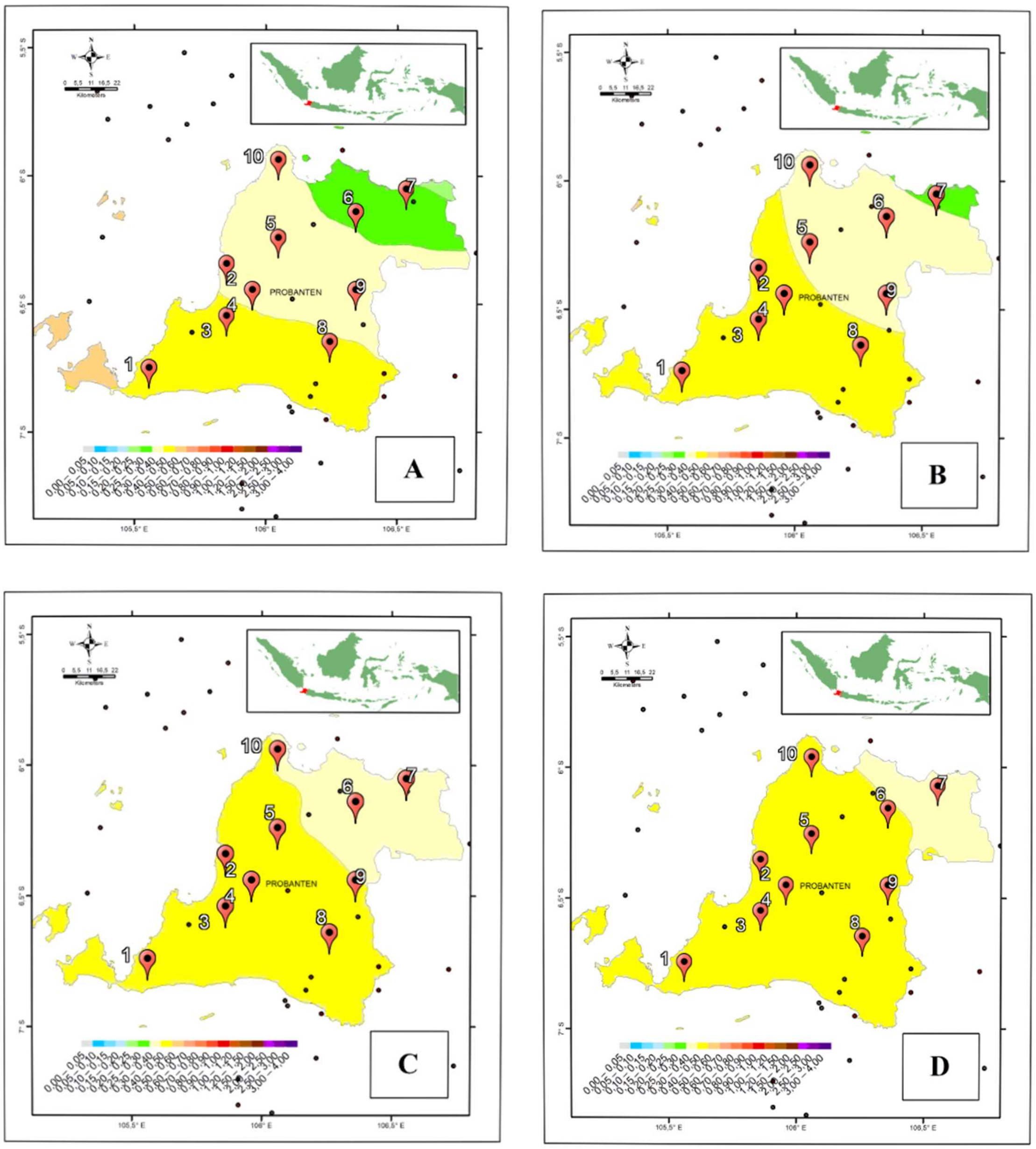

Figure 3 PSHA analysis of Banten area *background earthquake* sources with correlation distance: (A) 25 km correlation distance, (B) 50 km correlation distance, (C) 75 km correlation distance, (D) 100 km correlation distance.

In the PSHA analysis of Lampung area *background earthquake* sources with correlation distance of (A) 25 km, (B) 50 km, (C) 75 km, and (D) 100 km are shown in figure 4A-D. Figure 4A has PGA values in the range of 0.05-0.60 g. Figure 4B has PGA values with a range of 0.10-0.60 g. Figure 4C has PGA values with a range of 0.10-0.50 g. Figure 4D has PGA values with a range of 0.15-0.50 g.

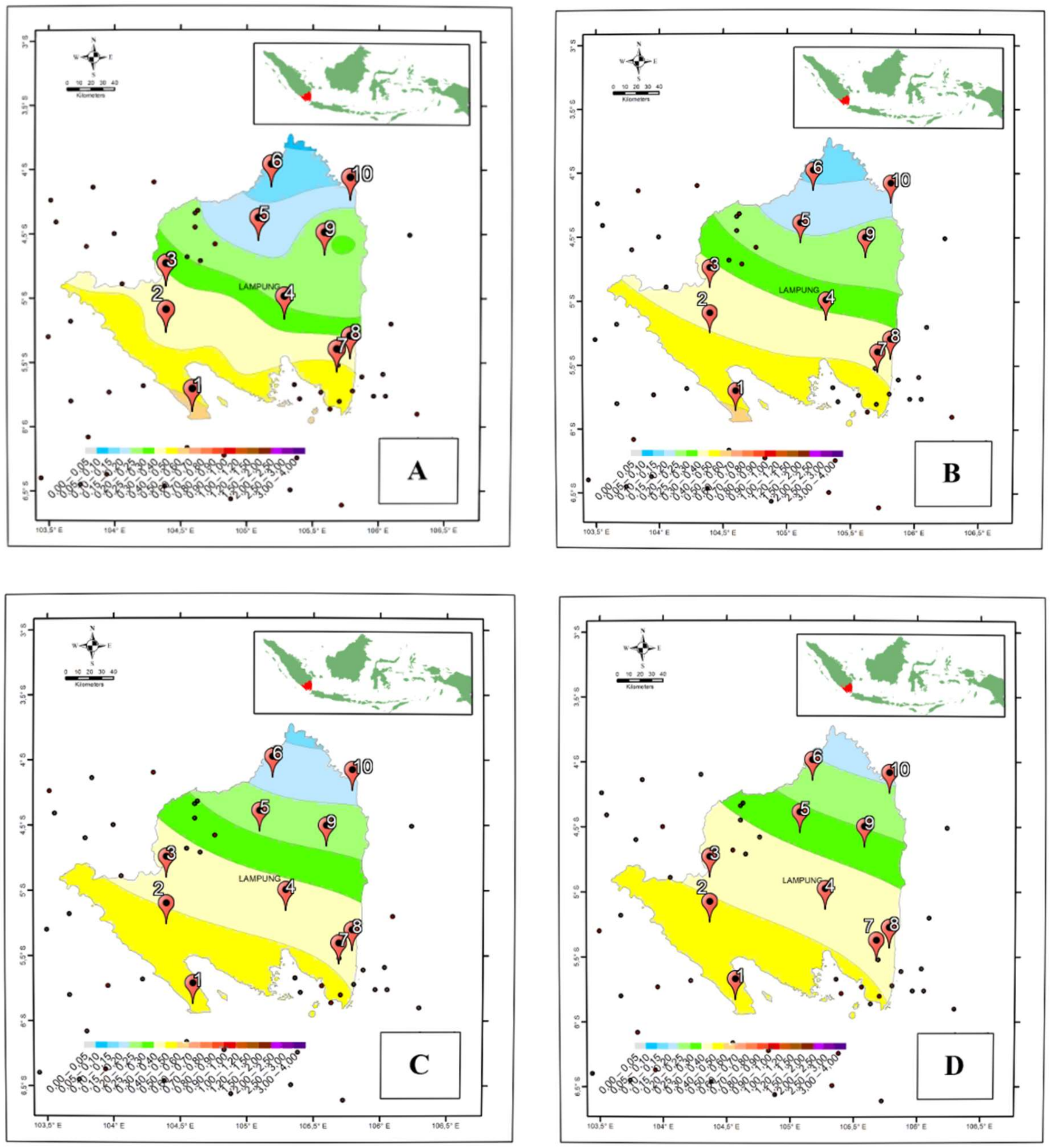

Figure 4 PSHA analysis of Lampung area *background earthquake* sources with correlation distance: (A) 25 km correlation distance, (B) 50 km correlation distance, (C) 75 km correlation distance, (D) 100 km correlation distance.

In the PSHA analysis of the *background earthquake* source in Southeast Sulawesi with correlation distance of (A) 25 km, (B) 50 km, (C) 75 km, and (D) 100 km are shown in figure 5A-D. Figure 5A has a PGA value with a range of 0.10-0.50 g. Figure 5B has a PGA value with a range of 0.15-0.50 g. Figure 5C has PGA values with a range of 0.20-0.40 g. Figure 5D has PGA values with a range of 0.20-0.40 g.

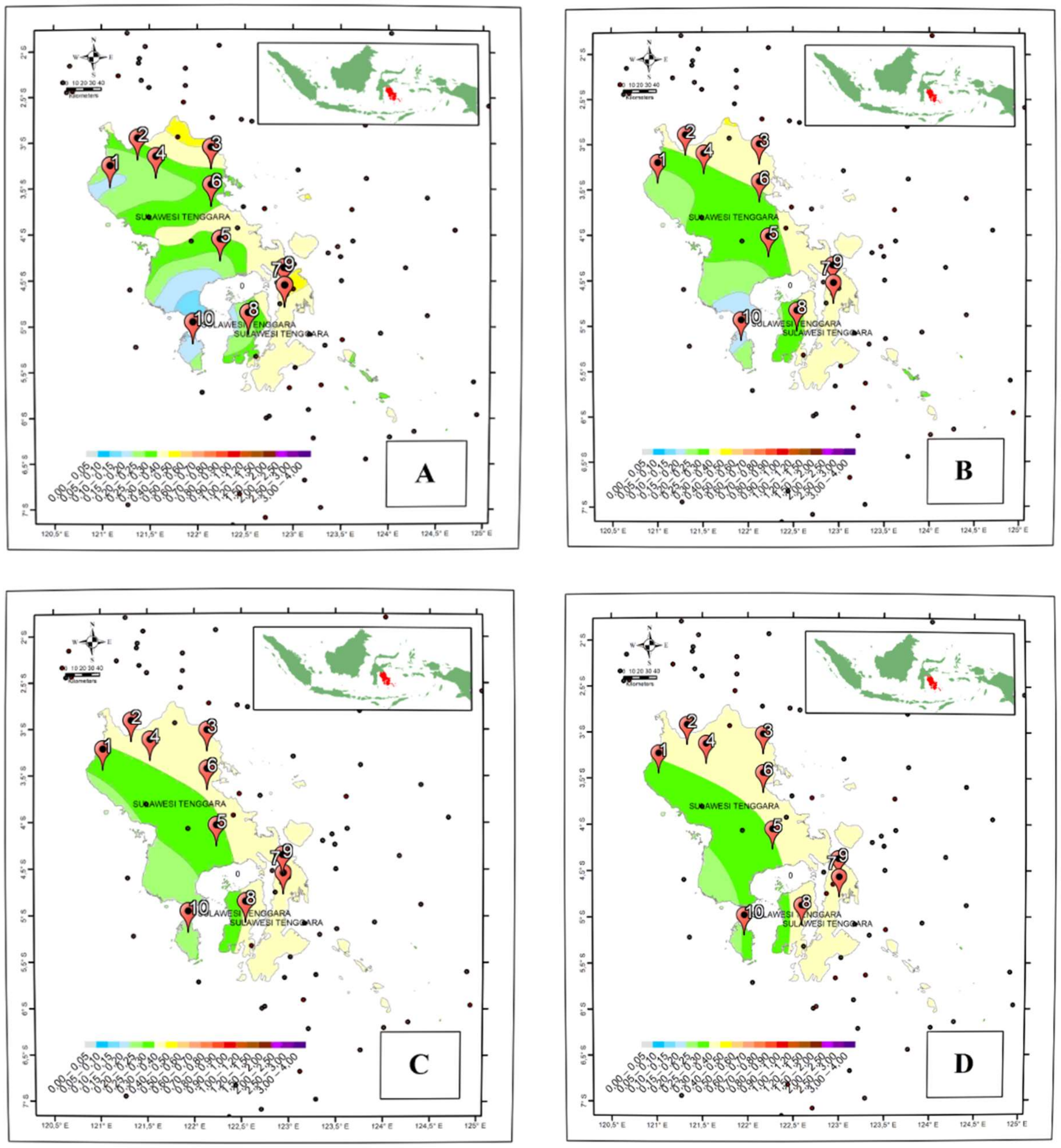

Figure 5 PSHA analysis of Southeast Sulawesi *background earthquake* sources with correlation distance: (A) 25 km correlation distance, (B) 50 km correlation distance, (C) 75 km correlation distance, (D) 100 km correlation distance.

In the PSHA analysis of *background earthquake* sources in the West Sumatra region with correlation distance of (A) 25 km, (B) 50 km, (C) 75 km, and (D) 100 km are shown in figure 6A-D. Figure 6A has a PGA value with a range of 0.20-0.50 g. Figure 6B has PGA values with a range of 0.20-0.50 g. Figure 6C has PGA values with a range of 0.20-0.50 g. Figure 6D has PGA values with a range of 0.20-0.50 g.

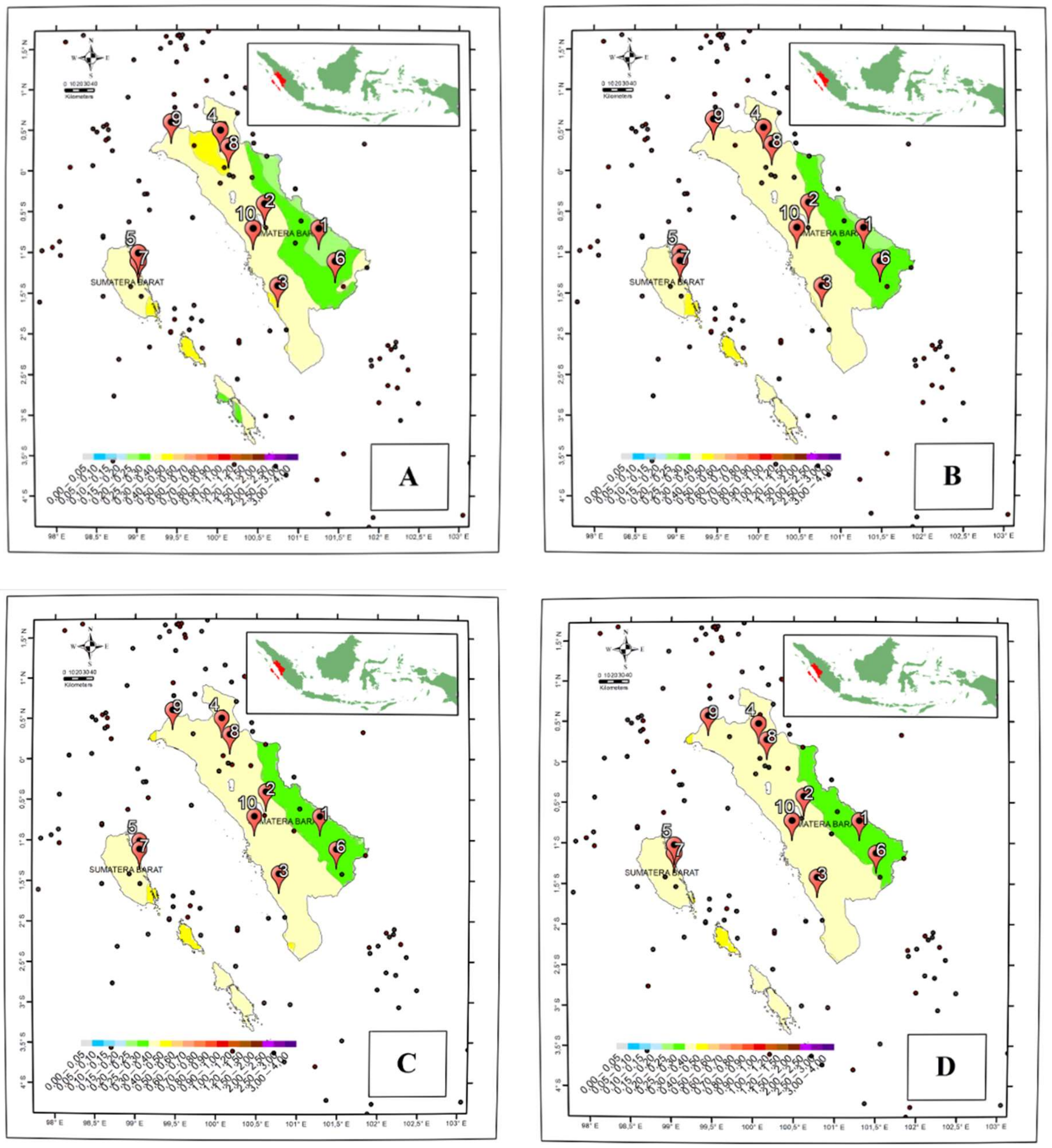

Figure 6 PSHA analysis of West Sumatra *background earthquake* sources with correlation distance: (A) 25 km correlation distance, (B) 50 km correlation distance, (C) 75 km correlation distance, (D) 100 km correlation distance.

In the PSHA analysis of the Gorontalo area *background earthquake* source with correlation distance of (A) 25 km, (B) 50 km, (C) 75 km, and (D) 100 km are shown in figure 7A-D.Figure 7A has PGA values in the range of 0.30-0.50 g. Figure 7B has a PGA value with a range of 0.40-0.50 g. Figure 7C has PGA values with a range of 0.40-0.50 g. Figure 7D has PGA values with a range of 0.40-0.50 g.

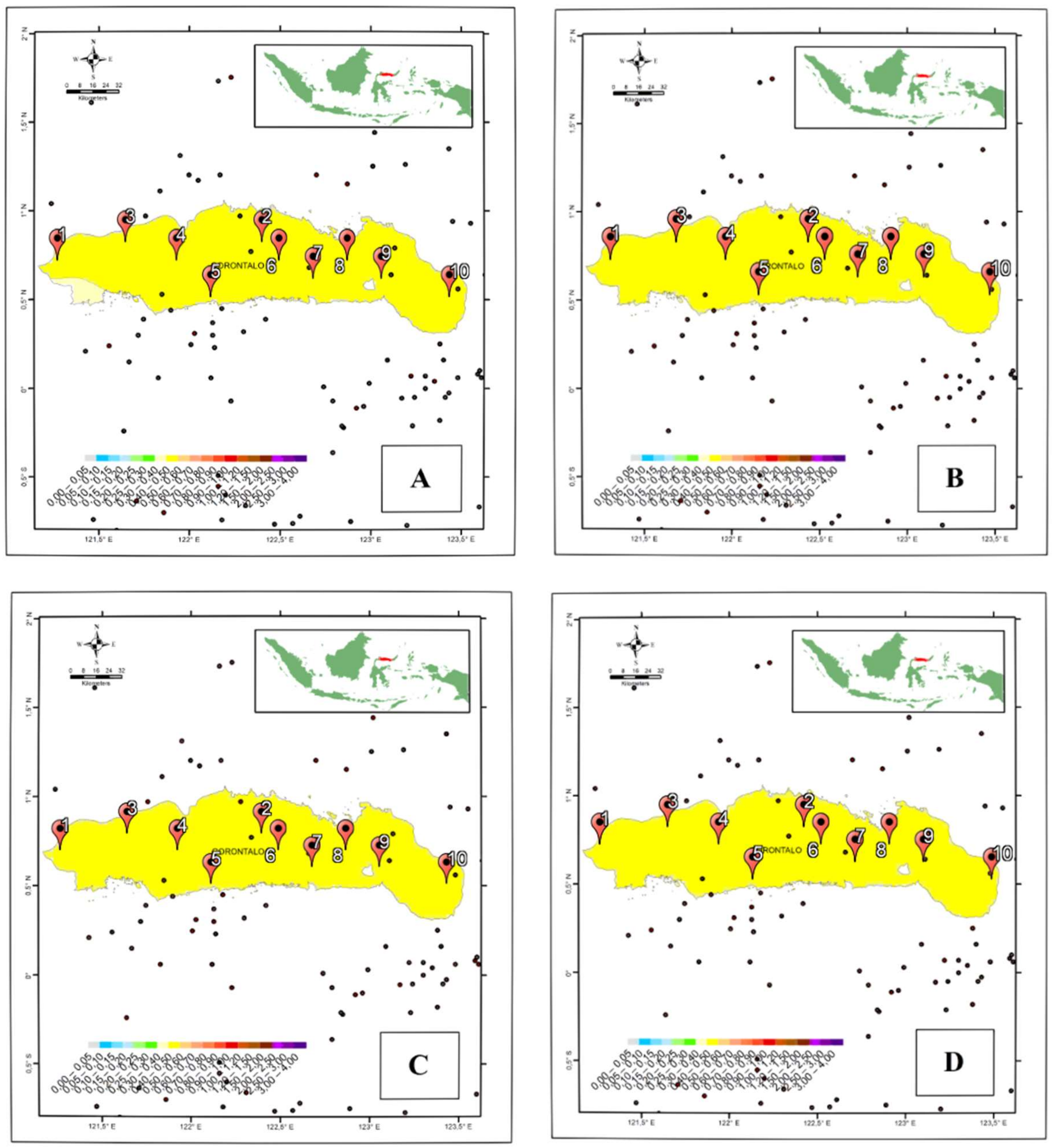

Figure 7 PSHA analysis of Gorontalo *background earthquake* sources with correlation distance: (A) 25 km correlation distance, (B) 50 km correlation distance, (C) 75 km correlation distance, (D) 100 km correlation distance.

In the PSHA analysis of the Bali *background earthquake* source with correlation distance of (A) 25 km, (B) 50 km, (C) 75 km, and (D) 100 km are shown in figure 10A-D. Figure 8A has a PGA value with a range of 0.30-0.60 g. Figure 8B has a PGA value with a range of 0.35-0.50 g. Figure 8C has PGA values with a range of 0.30-0.50 g. Figure 8D has PGA values with a range of 0.30-0.50 g.

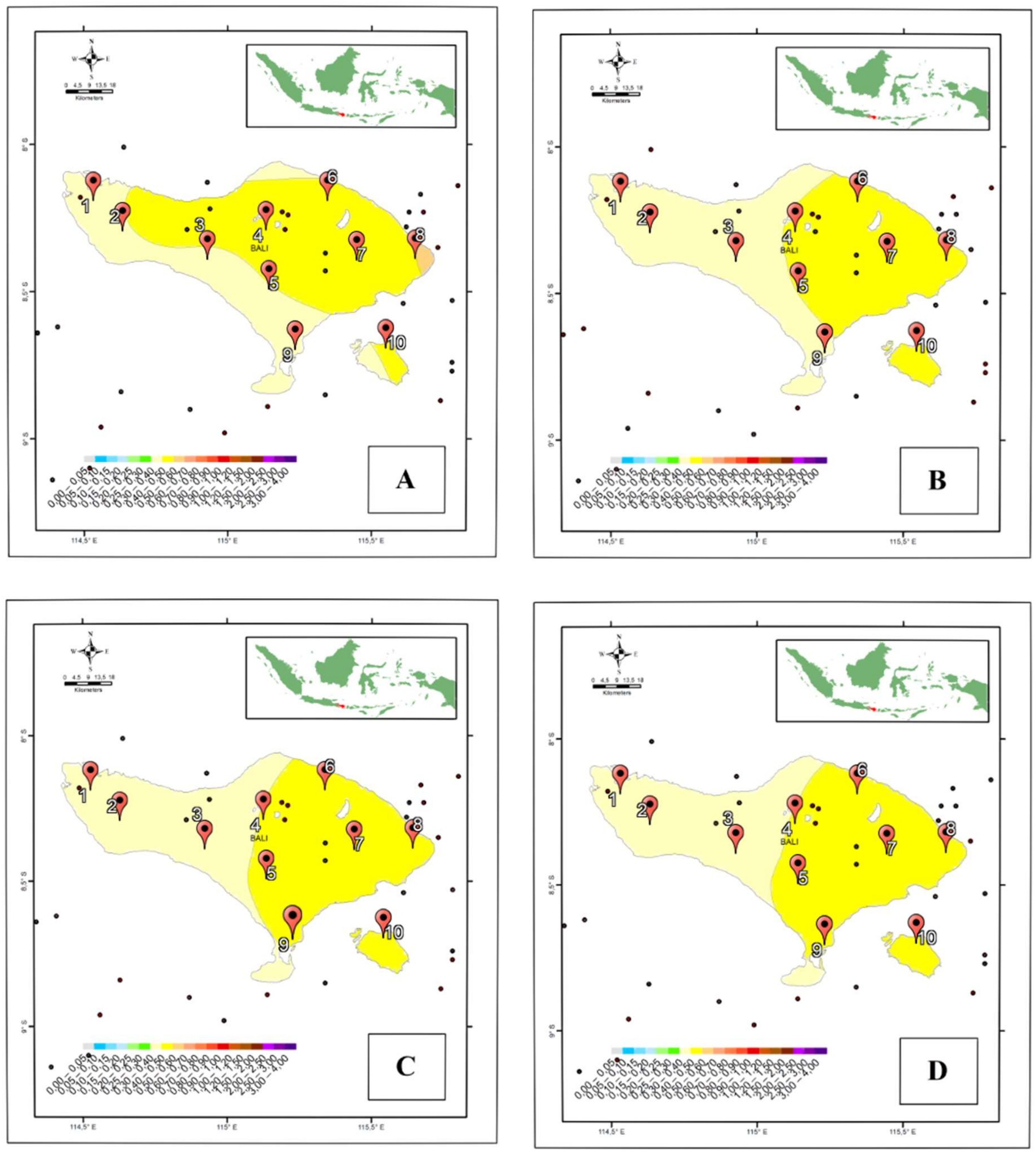

Figure 8 PSHA analysis of Bali *background earthquake* sources with correlation distance: (A) 25 km correlation distance, (B) 50 km correlation distance, (C) 75 km correlation distance, (D) 100 km correlation distance.

After obtaining the PGA value of the selected area, the next step is to select 10 location points that will be analyzed regarding changes in the correlation distance (R) value to the PGA value.

4. DISCUSSION

Based on the four PGA maps (figure 3A-D) produced by the PSHA analysis of Banten Province, the PGA of 10 points selected for the respective correlation distance (25 km, 50 km, 75 km and 100 km) is shown in Figure 9.

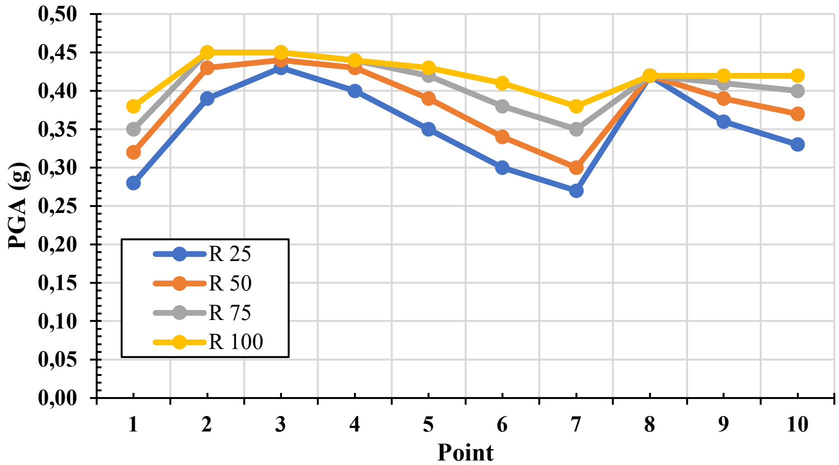

Figure 9 Graph of PGA values from 10 points in Banten Province

It can be seen that points 1, 2, 3, 4, 5, 6, 7, 9 and 10 have the same trend, i.e. with a correlation distance (R) of 25, they have the lowest PGA values compared to those with larger correlation distance. This is because these points are located in locations that have a history of earthquakes and are far enough away to have smaller PGA values. This is because these points are located in locations that have less earthquake history and are far enough away to have smaller PGA values. Meanwhile, at point 8, there is a phenomenon that all the PGA value of 0.42 g remain the same for all correlation distances. This is because point 8 is located in an area that has quite a lot of earthquake history as seen in Figure 5, thus different correlation distances has the same PGA value. The maximum PGA value of the 10 locations selected in Banten Province is 0.45 g obtained from correlation distance of 75 km and 100 km at location 3 and the minimum value at the 10 locations in Banten province is 0.27 obtained from correlation distance of 25 km at location 7.

Based on the four PGA maps (figure 4A-D) produced by the PSHA analysis of Lampung Province, the PGA of 10 points selected for the respective correlation distance (25 km, 50 km, 75 km and 100 km) is shown in Figure 10.

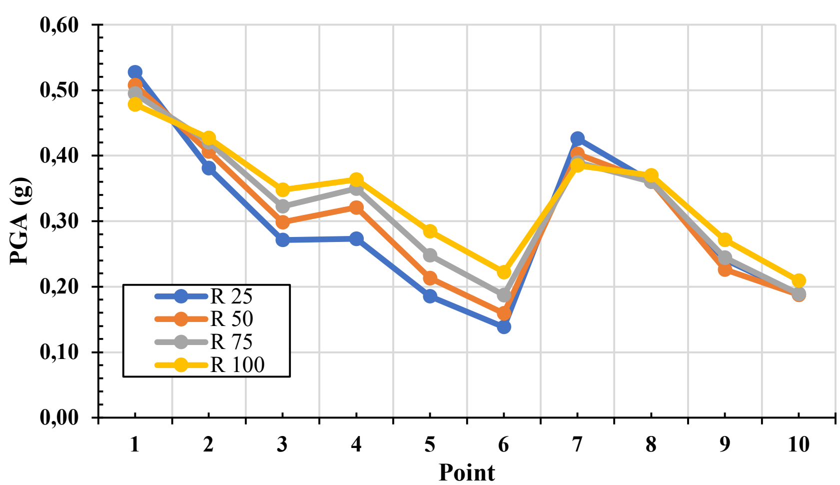

Figure 10 Graph of PGA values from 10 points in Lampung Province

It can be seen that points 2, 3, 4, 5, and 6 have the same trend as Banten province, i.e. the lowest PGA value correspond to the lowest correlation distance of 25 km. This is due to the distance between the location of these points and the source of the earthquake. Meanwhile, points 1 and 7 have PGA values that are greater than the other R values. This is because these locations are close to the center of many earthquake sources. The maximum value for points 2, 3, 4, 5, and 6 is 0.43 g, which is obtained from point 2 at correlation distance of 100 km. Meanwhile, the minimum value of points 1 and 7 is 0.38, which was obtained from correlation distance of 100 km.

Based on the four PGA maps (figure 5A-D) produced by the PSHA analysis of Southeast Sulawesi Province, the PGA of 10 points selected for the respective correlation distance (25 km, 50 km, 75 km and 100 km) is shown in Figure 11.

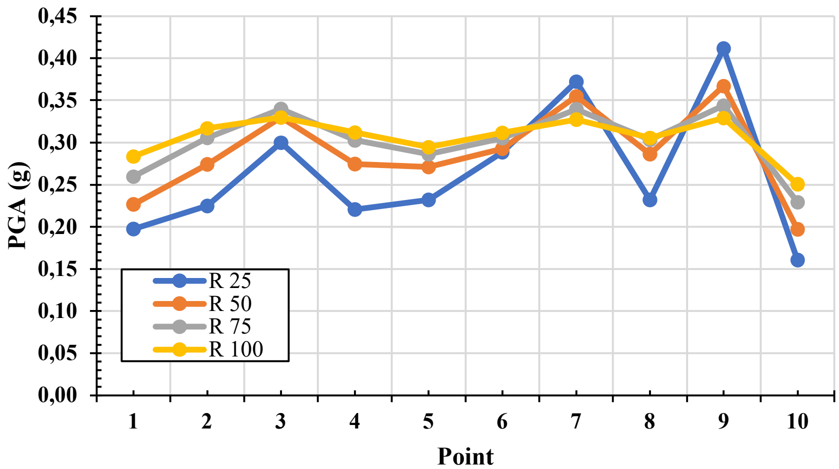

Figure 11 Graph of PGA values from 10 points in Southeast Sulawesi Province

It can be seen that points 1, 2, 3, 4, 5, 6, 8 and 10 have the same trend as before, i.e. the lowest PGA value correspond to the lowest correlation distance of 25 km. This is due to the location of these points, which are far enough away from the earthquake source to have smaller PGA values. Meanwhile, at points 7 and 9, the opposite phenomenon occurs, where the highest PGA values correspond to the lowest R value. This is because location 7 and 9 are located in close proximity to many earthquake source points, causing the 25 km correlation distance to have larger PGA values. The maximum PGA value at locations 1, 2, 3, 4, 5, 6, 8 and point 10 is 0.31 g at a correlation distance of 100 km. And for locations 7 and 9, the minimum PGA value is 0.33 g obtained from correlation distance of 100 km.

Based on the four PGA maps (figure 6A-D) produced by the PSHA analysis of West Sumatra Province, the PGA of 10 points selected for the respective correlation distance (25 km, 50 km, 75 km and 100 km) is shown in Figure 12.

Points 1, 2, 4, 5, 6, 7, 9, and 10 have the usual trend, i.e. the lowest PGA values correspond to the lowest correlation distance of 25 km. This is due to the fact that these locations are quite far from the earthquake source and the number of earthquake sources is small, resulting in smaller PGA values. This is due to the fact that the area around these locations has a considerable distance to the earthquake source and the number of earthquake sources is small, resulting in smaller PGA values. Meanwhile, at points 3 and 8, the opposite phenomenon occurs, with PGA values above the other R values. This is due to the fact that the locations at points 3 and 8 are located near areas with a large number of earthquake sources, causing them to have larger PGA values with a correlation distance of R 25. The maximum PGA value at locations 1, 2, 4, 5, 6, 7, and point 10 is 0.38 g Which is obtained based on the analysis of R 100. And for locations 3 and 9 have a minimum value of 0.34 g obtained based on R 100 analysis.

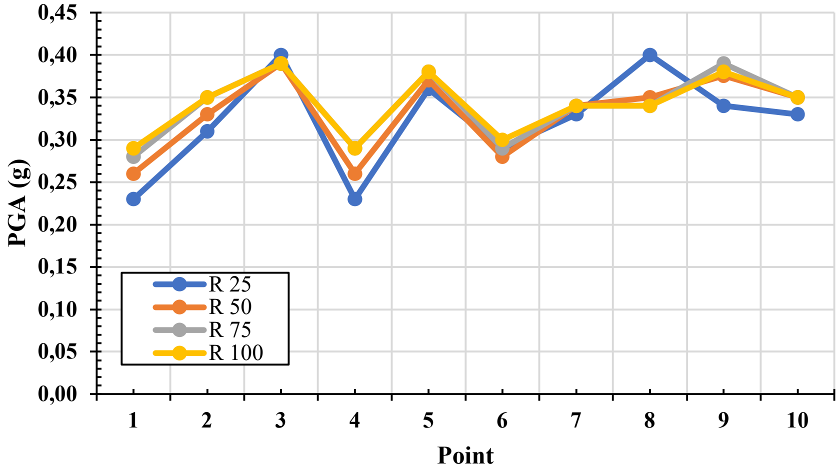

Figure 12 Graph of PGA values from 10 points in West Sumatra Province

Based on the four PGA maps (figure 7A-D) produced by the PSHA analysis of Gorontalo Province, the PGA of 10 points selected for the respective correlation distance (25 km, 50 km, 75 km and 100 km) is shown in Figure 13.

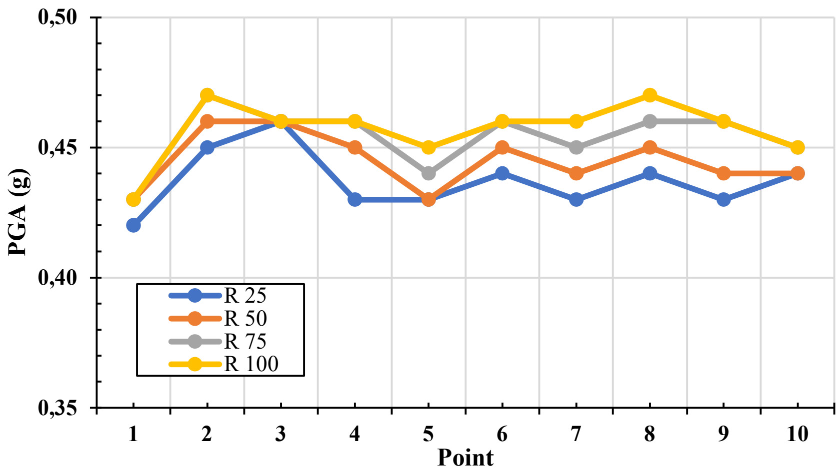

Figure 13 Graph of PGA values from 10 points in Gorontalo Province

It can be seen that points all the points except point 3 have the lowest PGA values correspond to the lowest correlation distance. As for location 3, all 4 of the correlation distances gave the same PGA value of 0.46g. This is because the *background earthquakes* in the area are evenly distributed, causing the correlation distance to not have a significant impact on the PGA calculation, resulting in the same PGA value.

Based on the four PGA maps (figure 8A-D) produced by the PSHA analysis of Bali Province, the PGA of 10 points selected for the respective correlation distance (25 km, 50 km, 75 km and 100 km) is shown in Figure 14.

For Bali Province, half of the points (1, 2, 4, 7 and 8) have higher PGA values at lower correlation distance. This is because there are many earthquake epicenters with fairly close distance around the 5 mentioned points. As for points 3, 9 and 10, the lowest PGA correspond to the lowest correlation distance of 25 km. This is because points 9 and 10 are located far from the epicenter of past earthquakes. The minimum PGA value of points 1, 2, 4, 7 and 8 is 0.37 g obtained from correlation distance of 50, 75 and 100 km. The maximum PGA value of points 3, 9 and 10 is 0.43g based on the analysis of correlation distance of 100 km.

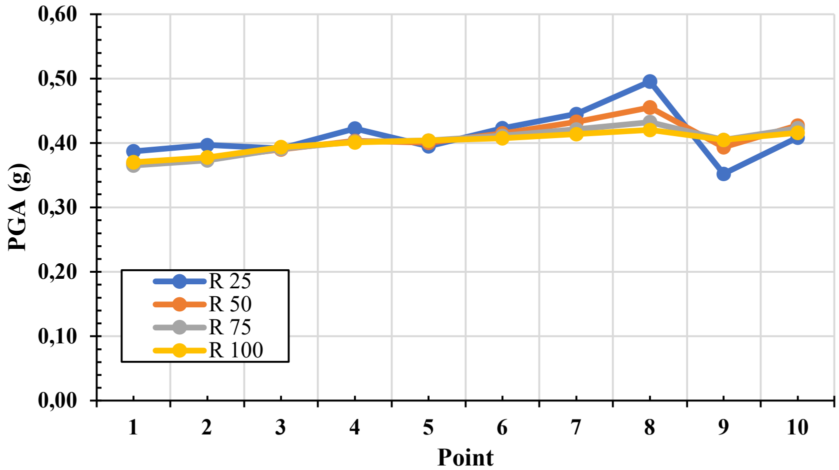

Figure 14 Graph of PGA values from 10 points in Bali Province

5. CONCLUSIONS

This research produces PGA maps of the six selected provinces and produces six graphs containing ten PGA value data with different correlation distances (R) from ten location points in each selected province. The results of the analysis of the ten points in each province are Banten Province has the maximum value of the PGA value of the 10 selected locations in Banten Province, namely 0.45 g obtained based on the analysis of R 75 and R 100 with the location at point 3 and the minimum value at 10 locations in Banten province 0.27 obtained based on the analysis of R 25 at point 7. Lampung Province has the maximum value of the PGA value of the 10 selected locations in Lampung Province, namely 0.51 g obtained based on the analysis of R 25 with the location at point 1 and the minimum value at 10 locations in Lampung province 0.14 obtained based on R 25 analysis at point 6. Southeast Sulawesi Province has the maximum value of the PGA value of the 10 locations selected in Southeast Sulawesi Province, namely 0.41 g obtained based on R 25 analysis with a location at point 9 and the minimum value at 10 locations in Southeast Sulawesi province 0.16 obtained based on R 25 analysis at point 10. West Sumatra Province has the maximum value of the PGA value of the 10 locations selected in West Sumatra Province, namely 0.40 g obtained based on the analysis of R 25 with locations at point 3 and point 8 and the minimum value at 10 locations in West Sumatra province 0.23 obtained based on the analysis of R 25 at point 1 and point 4. Gorontalo province has the maximum value of the PGA value of 10 selected locations in Gorontalo province is 0.47 g obtained based on the analysis of R 75 and R 100 with locations at point 2 and R 75 at point 8 and the minimum value at 10 locations in Gorontalo province 0.42 obtained based on the analysis of R 25 at point 1. Bali Province has the maximum value of PGA value from 10 selected locations in Bali Province, which is 0.50 g obtained based on R 25 analysis with the location at point 1 and the minimum value at 10 locations in Bali Province is 0.35 obtained based on R 25 analysis at point 9. The results of this study can be concluded that the difference in distance affects the resulting PGA value, where the closer the correlation distance (R) is to the *background earthquake* source, the greater the PGA value. Thus, at some points, smaller correlation (R) values have higher PGA values. However, with points far from the *background earthquake* source, the opposite occurs, with small correlation distances having smaller PGA values than PGA values with larger correlation distances. This is probably because the larger the R value, the more *background earthquakes* affect the PGA value at that location.

DISCLAIMER

The authors hereby declare that the research carried out is not a form of plagiarism and does not violate the law. The software used in the seismic analysis is the authors' modification of the original USGS software. Distribution of this modified software must be authorized by the authors. The use of modified software without the authors' knowledge is not our responsibility.

AVAILABILITY OF DATA AND MATERIALS

The data used in this study comes from PuSGeN which has been published in the 2017 Indonesian Earthquake Sources and Hazards Book.

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REFERENCES

Andrianto, B.Y., Manalu, J., and Warpur, M., 2023. Analysis Of The Level Of Earthquake Disaster Hazard In Sarmi Regency (In Indonesian). *Jurnal Portal Sipil*, 12(1), pp. 1-11.

Asrurifak, M., Irsyam, M., Budiono, B., Triyoso, W., Merati, W., & Sengara, W.I., 2009. Peta Spektra Hazard Indonesia Dengan Menggunakan Model Gridded Seismicity Untuk Sumber Gempa Background. *Proceeding of HAKI 2009*.

Gerstenberger, M.C., Marzocchi, W., Allen, T., Pagani, M., Adams, J., Danciu, L., Field, E.H., Fujiwara, H., Luco, N., Ma, K.F., Meletti, C., & Petersen, M.D., 2020. Probabilistic Seismic Hazard Analysis at Regional and National Scales: State of the Art and Future Challenges. *Reviews of Geophysics,* 58(2). https://doi.org/10.1029/2019RG000653

Ginting, R.A., Budi, A.P., Sunardi, B., and Sukanta, I.N., 2020. Analisis Kerawanan Seismik di Permukaan Tanah untuk Mitigasi Gempa Bumi di Kabupaten Majalengka Menggunakan Metode PSHA. *Proceeding of Seminar Nasional Fisika (SNF) 2020,* pp. 7-13.

McNamara, D.E., Petersen, M.D., Thompson, E.M., Powers, P.M., Shumway, A.M., Hoover, S.M., Moschetti, M.P., & Wolin, E., 2019. Evaluation of ground-motion models for USGS seismic hazard forecasts: Induced and tectonic earthquakes in the Central and Eastern United States. *Bulletin of the Seismological Society of America*, 109(1), pp. 322–335. https://doi.org/10.1785/0120180106

Mousavi, S.M., & Beroza, G.C., 2019. Bayesian-Deep-Learning Estimation of Earthquake Location from Single-Station Observations. *IEEE Transactions on Geoscience and Remote Sensing,* 58(11), pp. 8211-8224. https://doi.org/10.1109/TGRS.2020.2988770

Oktaviani, D.A., Satrio, M.I., Ramadhan, M.R.D., Syahbana, A.J., Sugianti, K., Jauhari, A., & Supriyanto., 2023. Distribution of seismicity hazard levels using PGA analysis with the PSHA method in the Ciletuh Geopark Area, Sukabumi, Indonesia. *BIO Web of Conferences*, 73. https://doi.org/10.1051/bioconf/20237304013

Pasau, G., & Tanauma, D.A., 2011. Pemodelan Sumber Gempa Di Wilayah Sulawesi Utara Sebagai Upaya Mitigasi Bencana Gempa Bumi. *Jurnal Ilmiah Sains,* 11(2), pp. 202-209.

Puteri, D.M., Affandi, A.K., Sailah, S., Hudayat, N., & Zawawi, M.K., 2019. Analysis of peak ground acceleration (PGA) using the probabilistic seismic hazard analysis (PSHA) method for Bengkulu earthquake of 1900 - 2017 period. *Journal of Physics: Conference Series*, 1282(1). https://doi.org/10.1088/1742-6596/1282/1/012054

Putu, I.D.P., 2020. Pemetaan dan Analisis Probabilistic Seismic Hazard Analysis (Psha) Radius 500 km Dari Denpasar. *Jurnal Geografi Gea*, 20(1), pp. 54-62. https://doi.org/10.17509/gea.v20i1.23299.g11794

Riyanti, A., & Rasimeng, S., 2020. Analisis Zona Bahaya Gempabumi Berdasarkan Metode Deterministik dan Pendekatan Geomorfologi Kota Padang Sumatera Barat. *Jurnal Geofisika Eksplorasi*, 5(2), pp. 101–115. https://doi.org/10.23960/jge.v5i2.26

Rohadi, S., 2015. Studi Seismotektonik Sebagai Indikator Potensi Gempabumi di Wilayah Indonesia. *Jurnal Meteorologi dan Geofisika*, 10(2), pp. 111-120.

Aprillianto, S., Santosa, B.J., and Sunardi, B., 2016. Ground Motion Modeling Wilayah Sumatera Selatan Berdasarkan Analisis Bahaya Gempa Probabilistik. *Jurnal Sains dan Seni ITS,* 5(2), pp. 129-133.

Syahbana, A.J., Goro, G.L., Saputra, O.F., Aditramulyadi, D.D., Irsyam, M., Asrurifak, M., & Hendriyawan, 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), pp. 3138–3148.

Thompson, E.M., McBride, S.K., Hayes, G.P., Allstadt, K.E., Wald, L.A., Wald, D.J., Knudsen, K.L., Worden, C.B., Marano, K.D., Jibson, R.W., & Grant, A.R.R., 2019. USGS near-real-time products—and their use—for the 2018 anchorage earthquake. *Seismological Research Letters*, 91(1), pp. 94–113. https://doi.org/10.1785/0220190207

Triyoso, W., Yudistira, T., & Sahara, D.P., 2020. Analysis of Changes in Seismicity Pattern for Probabilistic Seismic Hazard Analysis (PSHA) and Mitigation: Mapping Probability Difference before the Large Earthquake and Its Implementation in PSHA & Mitigation around Northern Sumatra. *Research Letter.* https://doi.org/10.21203/rs.3.rs-36859/v1

Wiens, D. A., 2001. Seismological constraints on the mechanism of deep earthquakes: temperature dependence of deep earthquake source properties. *Physics of the Earth and Planetary Interiors*, 127(1-4), pp. 145-163. https://doi.org/10.1016/S0031-9201(01)00225-4 .