Distribution of seismicity hazard levels using PGA analysis with the PSHA method in the Ciletuh Geopark Area, Sukabumi, Indonesia

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Abstract. The regional structure in Java Island, Indonesia, was influenced by the collisional activity of the Eurasian and Indo-Australian plates, which resulted from mélange rocks outcrops in Ciletuh. Ciletuh is one of the geo-tourism conservation areas included in the UGG (UNESCO Global Geoparks). This area is in the path of the Cimandiri Fault and the Sunda Strait Megathrust, resulting in a unique geological diversity and a place where the oldest rocks are exposed in West Java. In addition, the potential impact of seismicity on the Ciletuh geopark area is quite significant. The potential for seismicity can be analyzed and calculated. In this study, PGA (Peak Ground Acceleration) analysis on bedrock was conducted using the PSHA (Probabilistic Seismic Hazard Analysis) method. The data used for the PSHA method is in the form of background, fault, and megathrust provided by the National Earthquake Study Center (PuSGeN). This research shows that the PGA value in the Ciletuh Geopark area is influenced by how close it is to the location of the earthquake source. Pelabuhanratu Sub-district has the highest PGA value based on all earthquake sources when combined.

1. Introduction

West Java has much geological uniqueness due to its old tectonic activities. Various types of rocks, from sedimentary rocks, igneous rocks (extrusive and intrusive), and metamorphic rocks of various ages, can be found in this region[1]. This is influenced by the Indo-Australian Plate collision activity, which subducts under the Eurasian Plate[2]. On the island of Java, there are three directions of structural alignment: the Meratus Pattern, the Sundanese Pattern, and the Javanese Pattern[3]. Besides that, regional structures play an essential role

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in the many fault structures developed in West Java. They are still active today, namely the Cimandiri, Baribis, and Lembang Faults[4].

One uniqueness in West Java can be found in the Ciletuh Geopark Area, which has mélange rocks as one of the oldest rock groups. Melange rocks themselves are a group of pre-tertiary rocks formed by the mixing of various types of rocks, such as deep-sea sedimentary rocks (pelagic sediments), metamorphic rocks, and alkaline to ultra-basic igneous rocks in a trough and experiencing uplift[5]. This geopark is used for education, research, conservation, and economic activity through tourism development[6]. In addition, this area is also close to the Cimandiri Fault and the Sunda Strait Megathrust, which has resulted in the discovery of many geological sites, such as waterfalls.

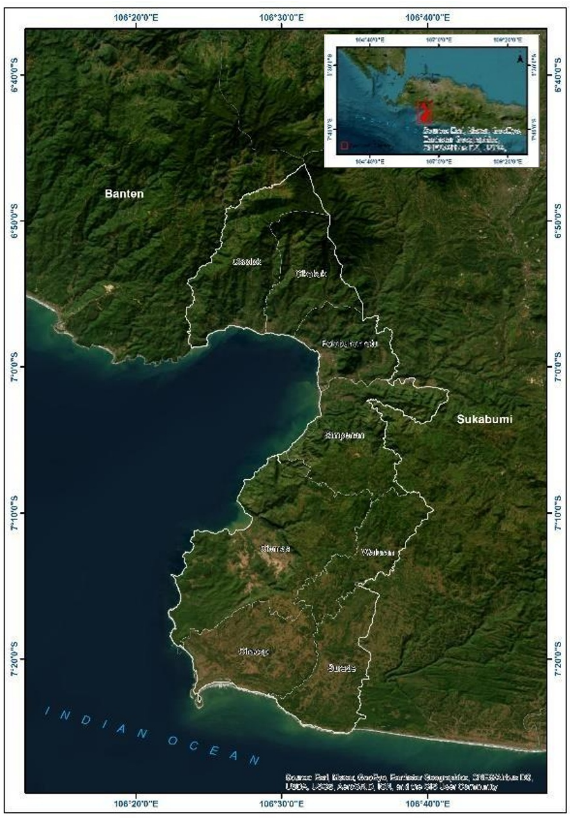


Fig. 1. Geopark Ciletuh Area

The uniqueness and diversity of these geological sites have pushed the Ciletuh Geopark Area to become one of the UGG or UNESCO Global Geoparks in 2017 and is characterized by Miocene-aged intrusive and extrusive igneous rocks. These igneous rocks are scattered along the coast, and some form small hills[6]. The Ciletuh Geopark area is located on the Geological Map of the Sheet Jampang and Balakembang. Geomorphologically, it is located in the Ciletuh Bay complex in the Southern Mountains zone of Java and has fluvial, structural, and marine formations[7]. The area, which is located in Sukabumi Regency, West Java, has an area of 126,100 hectares, covering 74 villages in 8 sub-districts that contain various tourist objects such as beaches and waterfalls.

Apart from this uniqueness, the potential for earthquakes arising from the tectonic conditions around the geopark area still haunts us. It was recorded several times that earthquake vibrations were felt in the Ciletuh Pelabuhan Ratu Geopark area from 2017-2022, with the intensity of the earthquake depth and the magnitude of the identified magnitude ranging from 3.3 to 6.9 Mw[8]. This can be a threat considering that the area is a tourist area with many geological sites. Based on the Technical Guidelines for Assessment of Geological Heritage Resources, damage to geological features can affect one of the assessment values, namely the degradation value. This can be a concern considering how valuable the geological sites are in the region[9].

The potential for seismicity must continue to be analyzed to minimize unwanted impacts. One way is calculating the level of bedrock shaking to find the PGA (Peak Ground Acceleration) values from various locations through the PSHA (Probabilistic Seismic Hazard Analysis) method[10]. The PSHA method can calculate and analyze the distribution of potential seismicity by considering several factors, such as the location and frequency of earthquakes. The stages be2gin with identifying the earthquake's source and characteristics that occurred in the area[11].

This paper aims to determine the distribution of potential seismicity in the Ciletuh Geopark area so that it can be used as a reference for developing or maintaining the Ciletuh Geopark area and its existing geological sites.

2. Methodology

This research is a quantitative study using the PSHA method to obtain PGA values which can then be used to determine the level of seismic hazard in the Ciletuh Geopark area. The PSHA method is a method that takes into account and combines earthquake data and parameters in the form of magnitude, location, and time of earthquake occurrence, which is then used to analyze probabilistic earthquake hazards[12][13]. This research began with the collection of earthquake data and parameters in the form of secondary data obtained from several catalogues, namely the USGS, the Meteorology and Geophysics Agency (BMKG), as well as the 2017 Indonesia Earthquake Source and Hazard Map compiled by the National Center for Earthquake Studies (PuSGeN). Apart from collecting data and parameters, the tools used for this research were also prepared in the form of software USGS-PSHA with FORTRAN language for calculations of hazard earthquakes using the probability method, *ArcMap* to visualize the calculation results of hazard earthquake, and Microsoft *Excel* for manufacturing hazard curve using PGA values.

Next is the identification of the source of the earthquake, which includes the seismicity's mechanism, zone, and location. The earthquake mechanisms used are background earthquake sources, subduction earthquake sources (megathrust), and fault earthquake sources [14] (Figure 2). The earthquake zone used in this study is an earthquake with a 0-300 km depth, which includes shallow and deep earthquakes. The distance to the location of the earthquake source used was selected according to needs, which has a radius of approximately 500 km from the outermost position of the study area (Geopark Ciletuh)[10].

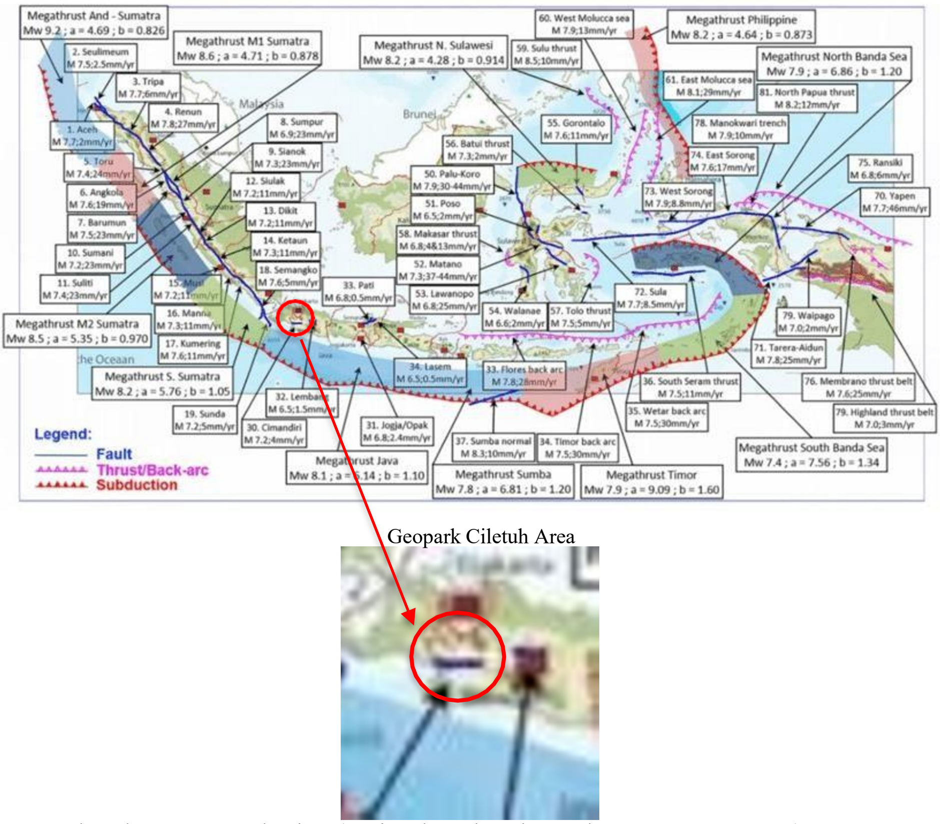


Fig. 2. Earthquake source mechanism (National Earthquake Study Center Team, 2017)

Seismic hazard analysis uses the software USGS-PSHA with FORTRAN language, which is open source. USGS-PSHA has a series of sub-programs in the form of filtrate, *HazFXnga7c*, *HazSUBXnga*, *AgridMLsm*, *HazgridXnga2*, and *HazallXL*[15]. Analysis of background earthquake sources is carried out by making input in the form of regional boundaries, correlation distances, distances between nodes, year data, minimum magnitude, and earthquake source files which will then be processed with sub-program *AgridMLsm*. The processing results are in the file, which will be processed again with the sub-program *HazgridXnga2* which produces an output of the binary form code. File binary code can then be directly processed using the sub-program *HazallXL* to get files with *.txt format, which can then be exported into *.csv format, which can be opened and visualized on ArcMap. Analysis of the source of the fault earthquake is the same as the analysis background. However, in the fault analysis, the input is processed with a sub-program Filtrate then the processing results are processed again with the sub-program *HazFXnga7c*. After that, the previous processing results are processed with the sub-program *HazallXL* and then visualized using ArcMap. Analysis of the subduction earthquake input source is processed using the sub-program *HazSUBXn*. Then, the results are directly processed using the sub-program *HazallXL* and visualized using ArcMap.

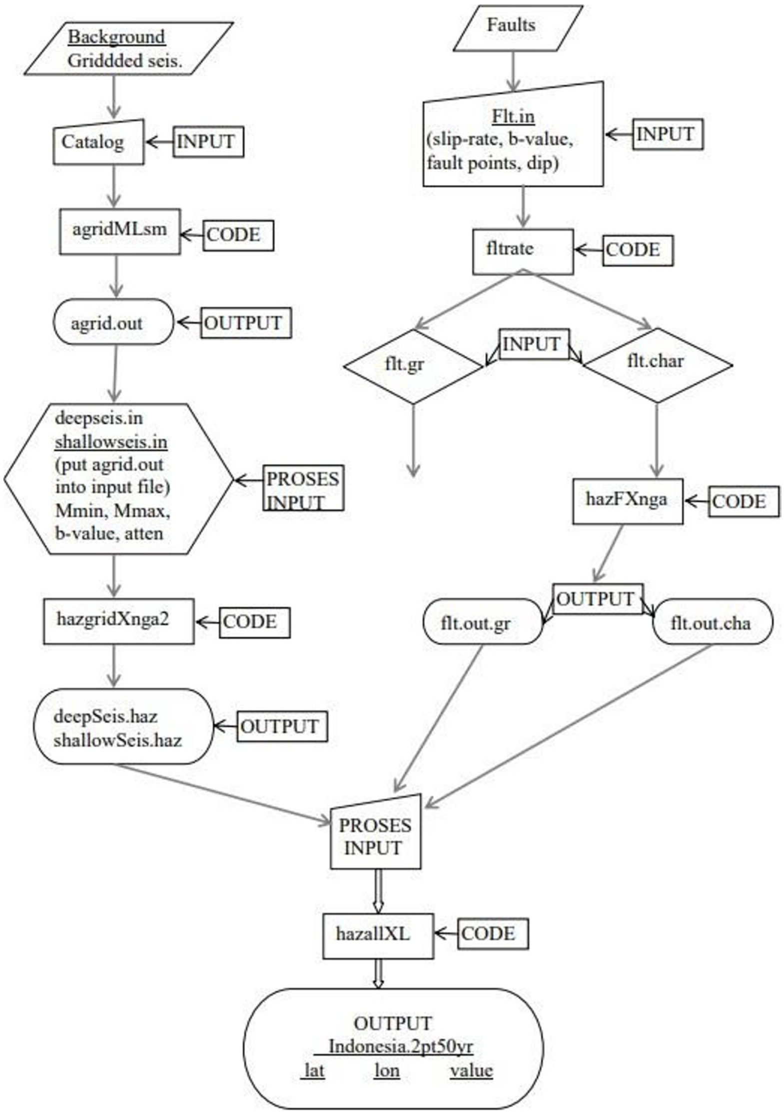
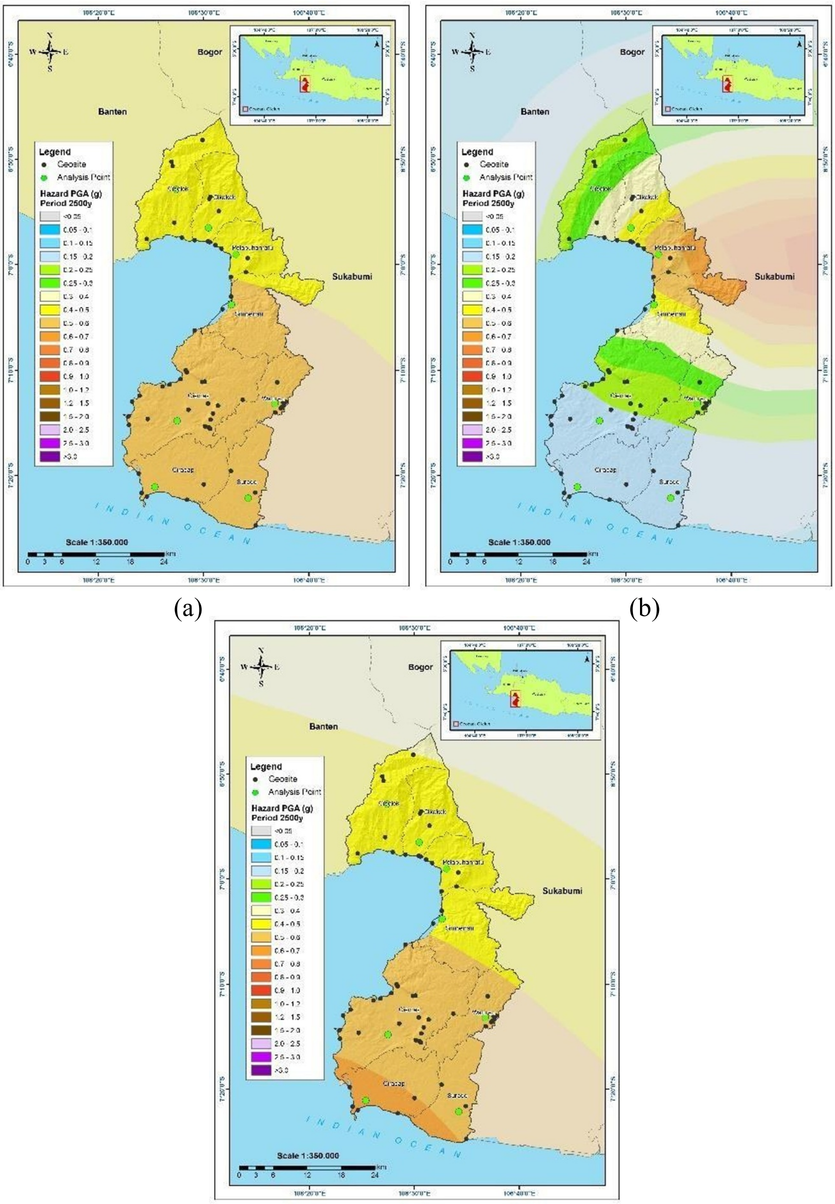


Fig. 3. Flow Chart USGS PSHA mechanism

Furthermore, a hazard curve was created in Microsoft Excel to determine the probability analysis in this study. The probability rates used in this study are 0.01, 0.004, 0.001, 0.0004, 0.0002, and 0.0001. Making the hazard curve is to analyze the return period with the value of the spectral acceleration (Sa or PGA) at each coordinate point close to several sites in several sub-districts included in the Ciletuh Geopark area. The sub-districts in this area are Cisolok, Cikakak, Palabuhanratu, Simpenan, Ciemas, Waluran, Ciracap, and Surade.

3. Result and Discussion

The analysis was carried out in each sub-district with points adjacent to each geo-site location. Based on the method described above, the analysis is carried out by considering each earthquake source, such as fault, megathrust, and background with a period of 2500 y. These results can be seen in the image below:



(a) (b) (c)

Fig. 4. Map of PGA in Geopark Ciletuh with return periods 2500 years with (a) background source, (b) fault source, and (c) subduction (megathrust) source using USGS PSHA

Based on Figure 4, it is known that each earthquake source influences each point location. At points adjacent to each of these earthquake sources, the PGA value tends to be larger. This is evidenced in the table below which manages to record the PGA value for each analysis point location compared to the earthquake source.

Table 1. PGA value based on earthquake sources with a return period of 2500y

Sub-district	Megathrust	Fault	Background
Cisolok	0.428544	0.300274	0.484553
Cikakak	0.456527	0.391471	0.494974
Palabuhanratu	0.4452	0.565853	0.492988
Simpenan	0.474439	0.520761	0.50158
Ciemas	0.585754	0.177631	0.516905
Waluran	0.517089	0.261	0.51164
Ciracap	0.621319	0.173244	0.514709
Surade	0.591266	0.166224	0.518267

Of the 8 sub-districts above, it was recorded that each sub-district had a PGA value based on the source of the earthquake. The location of the sub-district which is heavily influenced by the source of the subduction earthquake (megathrust) is Ciracap Sub-district, this is because the sub-district is very close to the Sunda Strait subduction zone. Meanwhile, the sub-district heavily affected by the source of the earthquake fault is Pelabuhanratu Sub-district because the western end of the Cimandiri fault starts from Palabuhanratu Sub-district which then stretches eastward. Then for the background earthquake source, it affects all sub-districts equally because the PGA value is almost the same in each sub-district, which ranges from 0.485 - 0.518 with the smallest PGA value in the northern region, namely in Cisolok Sub-district and the largest value in the southern region, namely Surade Sub-district.

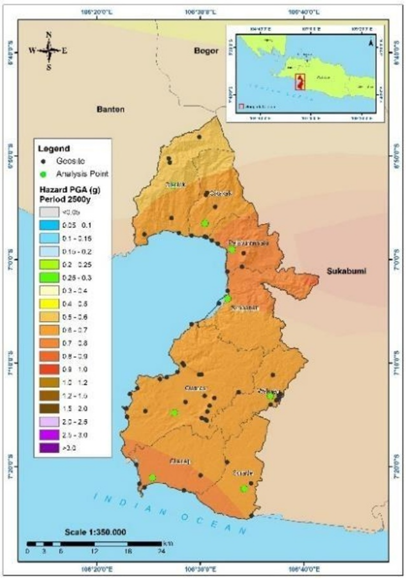


Fig. 5. All earthquake sources using USGS PSHA

After the analysis is carried out for each earthquake source, then an analysis is carried out by combining all earthquake sources in the form of megathrust, fault, and background into one. The results of combining all the earthquake sources affect changes in the PGA value at each location(Figure 5). The location with the highest PGA value is in Palabuhanratu Sub-district with a PGA value of 0.738 which is caused by the presence of a Cimandiri fault in that sub-district coupled with the influence of subduction and background sources. Then, Ciracap Sub-district, which was previously heavily influenced by subduction earthquake sources, is in 3rd place based on the PGA value of all earthquake sources. by subduction and background earthquake sources. Meanwhile, the smallest PGA value is found in Cisolok Sub-district because this sub-district is quite far from the source of subduction earthquakes and faults, and has the smallest background value among other locations. The sequence of locations with the largest to the smallest PGA values that are affected by all earthquake sources is Palabuhanratu, Simpenan, Ciracap, Surade, Ciemas, Cikakak, Waluran, and Cisolok. (Table 2).

Table 2. PGA value based on all earthquake sources with a return period of 2500y

Sub-district	All
Cisolok	0.600398
Cikakak	0.655012
Palabuhanratu	0.738568
Simpenen	0.730539
Ciemas	0.679414
Waluran	0.640082
Ciracap	0.705302
Surade	0.684978

The Ciletuh Geopark area has many geo-site locations that need to be maintained. The geo-site is scattered in every sub-district in the Ciletuh Geopark area. The most abundant geo-sites are found in Ciemas District. Earthquake hazards that can occur in Ciemas District are earthquakes caused by subduction and megathrust earthquake sources so that the area needs to receive more attention in disaster mitigation so that it can minimize the impact of earthquake disasters such as damage to geo-sites or tourists who become victims of disasters. In addition, some areas have a high hazard potential because these areas are affected by all earthquake sources, namely Palabuhanratu Sub-district, so this sub-district also needs to get more handling in earthquake mitigation caused by subduction, faults, and background.

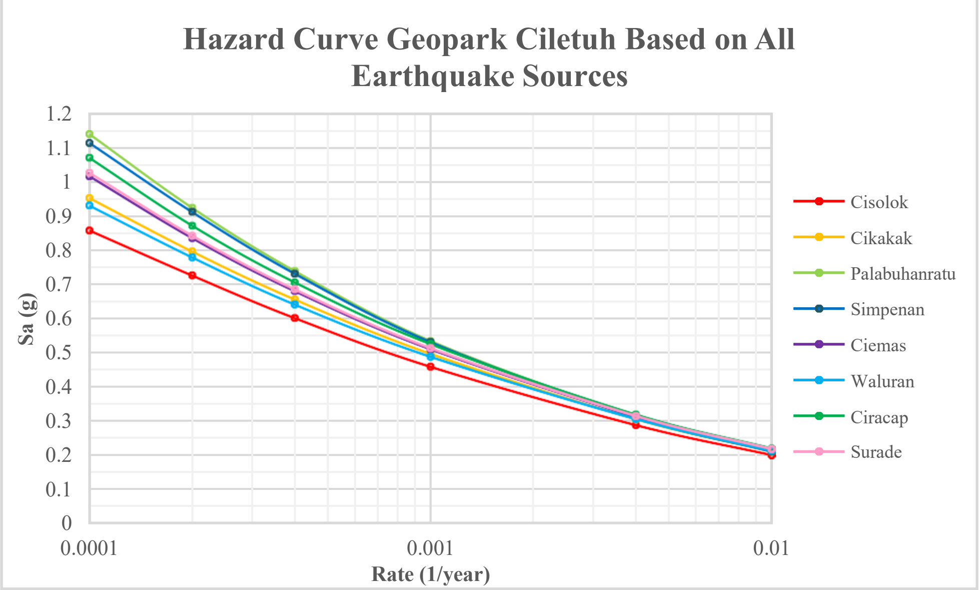


Fig. 6. Hazard curve Geopark Ciletuh based on all earthquake sources

The acquisition of this curve supports the results of previous data analysis, by combining all earthquake sources, starting from megathrust, fault, and background in eight districts with periods of 0.01, 0.004, 0.001, 0.0004, 0.0002, and 0.0001 (Figure 6). The results show that the PGA value obtained from the analysis shows that based on the period, the greater the number, the higher the PGA value. This is caused by the greater the return period, the greater the earthquake occurrence as indicated by the high PGA value obtained as the period increases.

4. Conclusions

Analysis of the level of earthquake hazard carried out in Ciletuh Geopark using the PSHA method shows that Palabuhanratu District has the highest PGA value among other sub-districts because the sub-district is affected by all earthquake sources such as subduction, fault, and background earthquake sources. In addition, there is a sub-district with the most sites among other sub-districts, namely Ciemas District, with a relatively high PGA value. Therefore, it is hoped that the two sub-districts will receive more attention regarding site maintenance and seismic disaster mitigation. The identified hazard curve also shows a constant increase in the PGA value with each additional period. This can be a challenge for the relevant government to always be on standby and prioritize mitigation activities considering that the Ciletuh Geopark area has many geological sites and is one of the tourist attraction areas.

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References

[1] I. Haryanto, Struktur Geologi Paleogen Dan Neogen *Bull. Sci. Contrib.* **4**, 1 p. 88–95 (2006)
[2] C. Darwin, This is a reproduction of a library book that was digitized by Google as part of an ongoing effort to preserve the information in books and make it universally accessible. https://books.google.com *Oxford Univ.* **XXX** p. 60 (1895)
[3] F. Hilmi and I. Haryanto, Pola Struktur Regional *Bull. Sci. Contrib.* **6**, 1 p. 57–66 (2008)
[4] RW Van Bemmelen, *The Geology of Indonesia. Vol. IA: General Geology of Indonesia and Adjacent Archipelagoes* US Government Printing Office (1949)
[5] SS Andriany, MR Fatimah and A. Hardiyono, Geowisata Geopark Ciletuh: Geotrek Mengelilingi Keindahan Mega Amfiteater Ciletuh (the Magical of Ciletuh Amphitheater) *Bull. Sci. Contrib.* **14**, 1 p. 75–88 (2016)
[6] A. Gindasari, MF Rosana and AD Haryanto, Karakteristik dan Petrogenesis Batuan Beku di Kecamatan Cisolok (Daerah Geopark Ciletuh-Palabuhanratu), Kabupaten Sukabumi *J. Geol. dan Sumberd. Miner.* **23**, 3 p. 141–153 (2022)
[7] MF Rosana, U. Mardiana, I. Syafri, N. Sulaksana and I. Haryanto, Geologi Kawasan Ciletuh, Sukabumi: Karakteristik, Keunikan, dan Implikasinya *Univ. Padjadjaran* (2006)

[8] FB Ar-rouf and F. Masitoh, Earthquake Hazard Analysis in Ciletuh Pelabuhan Ratu Geopark Area, West Java *Jambura Geosci. Rev.* **5**, 1 p. 42–50 (2023)
[9] Pusat Survei Geologi, *Petunjuk Teknis Asesmen Sumberdaya Warisan Geologi [Technical Guidelines for Assessment of Geological Heritage Resources]* (2017)
[10] C. Azwar, A. Syahbana, A. Sari, M. Irsyam, A. Pamumpuni, and I. Sadisun, "The Sensitivity of Maximum Magnitude Range Parameter in Bedrock Acceleration Calculation for 2500 Years of Return Period, Case Study: Bengkulu Province, Indonesia," presented at The IOP Conference Series: Earth and Environmental Science, IOP Publishing, (2021)
[11] DM Puteri, AK Affandi, S. Sailah, N. Hudayat and MK Zawawi, Analysis of peak ground acceleration (PGA) using the probabilistic seismic hazard analysis (PSHA) method for Bengkulu earthquake of 1900 - 2017 period, *J. Phys. Conf. Ser.* **1282**, 1 (2019).
[12] P. S. G. N. (PuSGeN), P. L. P. and P. (Puskim), B. P. and P. (Balitbang), and K. P. U. and P. R. (PUPR), *Earthquake Source and Danger Map of Indonesia in 2017*. (2017).
[13] AJ. Syahbana, P. Iqbal, M. Irsyam, M. Asrurifak, and H. Hendriyawan, "Smoothed gridded seismicity effect for land-use development, case study: Kalimantan Island, Indonesia," vol. **36**, no. 3, pp. 115–126, (2021).
[14] U. Azmiyati, "Analysis of the Maximum Ground Vibration Acceleration Due to Earthquakes in the Nusa Tenggara Region Using the Probabilistic Seismic Hazard Analysis (PSHA) Method, "*JISIP (Journal of Social Sciences and Education)*, vol. **5**, no. 1, pp. 331–339, (2021).
[15] S. Harmsen, "USGS Software For Probabilistic Seismic Hazard Analysis (PSHA)," *United States Geol. Surv. (USGS), USA.*, no. June 2007, (2007).