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Analysis of return period and seismic risk of shallow earthquake occurrence in Cianjur and surrounding areas

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ABSTRACT

Determination of the seismic risk and return period of shallow earthquakes in Cianjur and surrounding areas is very important as a reference in earthquake disaster mitigation programs. Within this return period, structural and non-structural conditions can be prepared in stages that are ready to face disasters if the earthquake recurs. In this study used the least squares statistical method to determine the relationship between frequency and magnitude, level of risk, and earthquake return period. The earthquake data used in this study is sourced from the earthquake catalog of the United States Geological Survey (USGS) spanning 50 years (1973 – 2023). A total of 57 shallow earthquakes that occurred in Cianjur area and its surroundings at coordinates (06°-08°S and 106°-108°E) with magnitude greater or equal to 5.0 at a depth of 0-60 km were used as sample data. Based on the results of data processing and analysis, the return periods are 3.17 to 29.1 years for earthquakes with magnitudes between 5.0 and 6.0, and 29.1 to 267.38 years for earthquakes with magnitudes between 6.0 and 7.0.. Earthquake risk for 10 to 20 years with magnitude greater than 5.0 is 95.74 to 99.82 %, with magnitude greater than 6.0 is 20.09 to 49.70 %, and with magnitude 7.0 is 3.67 to 7.21 %. From the results of processing and analysis of the earthquake data, it shows that the Cianjur area and its surroundings are earthquake-prone areas with a high risk.

Keywords:
Cianjur; least square; earthquake risk; return period; disaster mitigation.

Introduction

The subduction zone between the Indo-Australian and Eurasian Plates located in the South of Java is not only a source of earthquakes, but also produces faults on the island of Java (Ariyanto et al., 2023). These active faults on land are the source of shallow and destructive earthquakes that often result in disasters. Of the six provinces on the island of Java, West Java is an area frequently hit by earthquakes.

Java Island is in close proximity to the active tectonic plate boundary, which separates the Sunda Plate to the north and the Australian Plate to the south. Along the boundary marked by the Sunda Trench, the northward movement of the Australian Plate results in subduction beneath the Sunda Plate (Ariyanto et al., 2023).The subduction zone is capable of producing earthquakes up to a magnitude of 8.7, while the Australian Plate can also produce deep earthquakes from the lithosphere downwards (intraslab earthquakes) off the coast of Java Island.

The subduction zone produced two destructive earthquakes and tsunamis in 2006 and 1994. An intraslab earthquake in 2009 also caused severe damage. Long before that, throughout history there were recorded earthquakes in 1844 and 1910 in the Cianjur area, which were repeated again in 1912. There were earthquakes again on November 2, 1968 and February 10, 1982 with strengths of M 5.4 and M 5.5 respectively. On July 12, 2000, an earthquake also occurred in the area around Cianjur-Sukabumi which resulted in 1900 houses being seriously damaged (BMKG, 2022).

The last earthquake occurred in the Cianjur area on Monday, November 21 2022, at 13:21:10 local time with a magnitude of 5.6. The earthquake was felt in Cianjur V-VI MMI

(Modified Mercalli Insensity); Garut and Sukabumi IV-V MMI; Cimahi, Lembang, Bandung City, Cikalong Wetan, Rangkasbitung, Bogor and Bayah with an intensity scale of III MMI; South Tangerang, Jakarta and Depok with an intensity scale of II-III MMI (Supendi et al., 2022)

The Cianjur area is crossed by the Cimandiri Fault, exposing the area to the risk of earthquake disasters. Several earthquakes have occurred on the Cimandiri Fault with a magnitude of 5.5 in 1982, 5.4 in 2000, and in 1900 with an intensity VII MMI scale (Supendi et al., 2022). Based on the conditions above, this research aims to provide information to the public that Cianjur and its surroundings are an area prone to earthquake hazards. Therefore, this research is very important so that the public can increase awareness of the risk of a recurrence of the earthquake disaster in the Cianjur area.

To analyze the risk of earthquake hazards, several methods can be employed, including microzonation which has been implemented in the Bandung Basin (Sari & Fakhrurrozi, 2020), Jakarta (Irsyam et al., 2008), and Tasikmalaya, West Java (Soehaimi et al., 2022). In addition, determining the risk of earthquake hazard can also be done using the Peak Ground Acceleration (PGA) method. Research using this method has been carried out in the Padang and Bengkulu areas (Triyoso et al., 2020) as well as the Indonesian region (Putra et al., 2012).

Risk analysis and return period determination to anticipate the occurrence of earthquakes have been conducted in various regions, including the Bengkulu area (Patrisia et al., 2019), along the Sumatra-Andaman subduction area (Pailoplee, 2017), Aceh (Jumila et al., 2019), and Kathmandu, Nepal (Shrestha, 2019)

Methods

Data obtained from the earthquake catalog of the United States Geological Survey (USGS). The research location is in Cianjur and its surroundings with coordinates 06° to 08° South Latitude and 106° to 108° East Longitude (figure 1) (Supendi et al., 2022). Earthquake data analyzed in this study are earthquake data with a magnitude of greater or equal than 5.0. The data time period is from 1973 to 2023 or around 50 years (figure 2) (United States Geological Survey [USGS], 2023). Basic Data of Shallow Earthquakes is shown in table 1. From the earthquakes basic data (table 1) are grouped as in table 2.

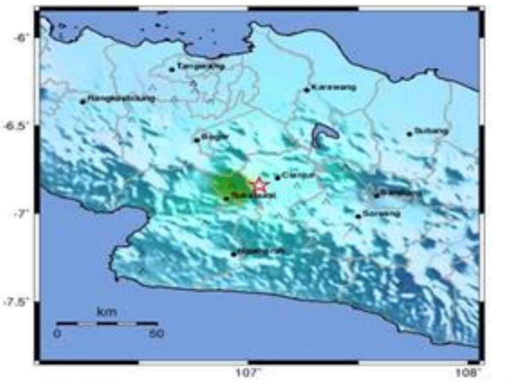

Figure 1. Location of research area (Supendi et al., 2022)

Figure 2. Distribution of shallow earthquakes (United States Geological Survey [USGS], 2023)

Table 1. Basic Data of Shallow Earthquakes

No	Year	Month	Date	Time(GMT)	Lat	Long	Depth (km)	Magnitude
1	1975	2	7	04-05-24,5	6.69S	106.68E	27	5.6
2	1977	8	1	07-07-26.9	8.17S	107.64E	52	5.7
3	1977	8	14	21-38-51.5	7.76S	107.57E	33	5.7
…	………	….	….	……………	…….	….	…..	….
57	1979	1	1	13-39-15.0	7.21S	106.04E	33	5.9

Table 2. Shallow Earthquake Frequency

No	Magnitude	Frequency
1	5.0 - 5.2	26
2	5.3 - 5.5	22
3	5.6 - 5.8	4
4	5.9 - 6.1	5
	Total	57

The method used in this research is the Least Square Method. The general equation of the least squares method is:

$$Y = a + bX$$

where Y = dependent variable, X = independent variable, and a, b = constant.
This method is used to determine the constants a and b in the relationship equation between the frequency and magnitude of earthquakes (Yuliastuti, 2018).

In earthquake statistics the constant a is a physical parameter whose magnitude depends on the period, area and seismic activity of the observation area. While the constant b is a physical parameter that is influenced by the characteristics of the local rocks (Yuliastuti, 2018). Furthermore, by knowing these constants, seismicity index parameters, return periods and the risk of earthquakes occurring at certain time intervals can be determined.

Relationship of Frequency and Earthquake Magnitude.

To determine the relationship between frequency and magnitude of earthquakes, the Gutenberg-Richter empirical equation (Gutenberg and Richter, 1954) is used:

$$\text{Log } N(M) = a - bM$$

where a dan b = constants, M = magnitude, and N = frequency.

For shallow earthquakes with a depth of less than 60 km (h < 60 km) a data format is prepared as in table 3.

Table 3. Earthquake Frequency and Midpoint

No.	Magnitude	Midpoint (Xi)	Freq (N)	LogN (Yi)
1	5.0 – 5.2	5.1	26	1.41497
2	5.3 - 5.5	5.4	22	1.34242
3	5.6 – 5.8	5.7	4	0.60206
4	5.9 – 6.1	6	5	0.69897
Total		22.2	57	4.05842

From the earthquake data in table 3 above, the values for:
$n = 4$
$\sum Xi2 = 123.66$
$\sum Xi = 22.2$
$\sum Yi2 = 4.65570$
$\sum Yi = 4.05842$
$\sum XiYi = 22.09098$

To calculate the constant b and a used the equation of the least square method:

$$b = \frac{n\sum(Xi.Yi) - (\sum Xi).(\sum Yi)}{n\sum Xi^2 - (\sum Xi)^2}$$

To calculate the constant a, use the formula:

$$a = \frac{\sum Yi - b\sum Xi}{n}$$

To determine the correlation coefficient between the frequency and magnitude of shallow earthquakes, the formula is used:

$$r = \frac{n\sum(Xi.Yi) - (\sum Xi).(\sum Yi)}{\sqrt{(n\sum Xi^2 - (\sum Xi)^2)(n\sum Yi^2 - (\sum Yi)^2)}}$$

Seismicity Index.

The seismicity index is a quantity that shows the total number of earthquake events that have occurred within a certain period of time with a magnitude greater than a certain magnitude in a research area. Calculation of the seismicity index of earthquakes with M ≥ 5.0, M ≥ 6.0 and M ≥7.0 with shallow depths (h < 60 km) uses the empirical formula (Peter Welker, 1965):

$$N1\ (M \geq M0) = 10^{(a - log(b\ ln\ 10) - log\ \Delta t\ ) - bMo}$$

The results of the calculation of the seismicity index can be seen in table 4.

Table 4. Seismicity Index of Shallow Earthquake

Magnitude	Seismicity Index
N1 (M ≥ 5.0)	0.31553
N1 (M ≥ 5.2)	0.20251
N1 (M ≥ 5.3)	0.16225
N1 (M ≥ 5.5)	0.10414
N1 (M ≥ 5.6)	0.08343
N1 (M ≥ 5.8)	0.05355
N1 (M ≥ 5.9)	0.04291
N1 (M ≥ 6.0)	0.03437
N1 (M ≥ 6.5)	0.01135
N1 (M ≥ 7.0)	0.00374

Earthquake Return Period

Earthquakes that have occurred in one place can be predicted when they will occur again in the same place. With statistical methods this can be determined to reduce the damage that may occur. To obtain the average return period for earthquakes, it can be calculated using the following empirical equation (Peter Welker, 1965):

$$\theta(M \geq M_0) = \frac{1}{N1(M \geq M_0)}$$

where Mo is the specified magnitude and N1(M>Mo) is the number of earthquakes with a magnitude greater than a specified magnitude.

Earthquake Risk

Earthquake risk level is the possibility of a destructive earthquake occurring at a certain time in a place. Earthquake risk level values are very useful information for disaster mitigation programs (Asnita et al., 2016). To calculate the level of earthquake risk with M ≥ 5.0, M ≥ 6.0 and M ≥ 7.0, can be used the empirical equation (Peter Welker, 1965):

$$P(M \geq M_0 T) = \left(1 - e^{-N1(M \geq M_0)T}\right)$$

where Mo is a certain magnitude and the time period T is between 10 and 100 years.

Results and Discussions

Previous researchers carried out an analysis of the risk of an earthquake disaster in West Java in 2015 based on calculations of maximum surface ground acceleration (Sutrisno & Perdana, 2015). From the results of this research, the Sukabumi, Cianjur and surrounding areas have the highest surface land acceleration prices compared to other areas.

Then in 2021 research was also carried out on earthquake risk based on earthquake coefficient analysis in Banten, DKI Jakarta and West Java Provinces (Sutrisno & Budiono, 2021). From the results of this study it was also reported that the Sukabumi area and its surroundings had the highest risk factors.

From the research report of the two researchers above, the area with the highest risk is Sukabumi and its surroundings. This area is close to Cianjur so it does not rule out the possibility that Cianjur also has a fairly high level of earthquake risk. It is proven that in 50 years in Cianjur there have been 57 shallow earthquakes (table 3) including a destructive earthquake with a magnitude of 5.6 which occurred on November 21, 2022 and caused many victims.

From the data obtained, the Cianjur area and its surroundings are an active earthquake area, with a high level of seismicity and dominated by smaller earthquakes. Of the 57 earthquake data dominated by earthquakes with magnitude 5.0 to 5.2 about 26 times and earthquakes with magnitude 5.3 to 5.5 about 22 times.

Judging from the distribution of epicenters (figure 2), it can be seen that Cianjur and its surroundings are earthquake-prone areas. The pattern of distribution of the hypocenter the further north the shallower it is in accordance with the number of earthquakes on land originating from the Cimandiri fault with a depth of approximately 10 km.

Analysis a and b Value

The result of the calculation of constant a is 6.358 shows that the study area has high seis micity. Meanwhile the results of the calculations obtained the constant b =0.96278. From the constant values a and b, the relationship between earthquake frequency and magnitude can be expressed in the equation:

$$\text{Log N (M)} = 6.358 - 0.96278\,\text{M}$$

with the correlation coefficient $r = -0.8805$.

Knowing the significant b value (0.96278) indicates that the Cianjur area and its surroundings have layers of brittle rock that break easily, resulting in a relatively low ability to absorb fault energy. This can be seen from the tendency for small magnitude earthquakes to occur with a high frequency of occurrence (table 2).

The results of research carried out before the damaging earthquake occurred on November 21, 2022 obtained b value of 0.538 (Munandar & Sulsaladin, 2022). This figure is smaller than the b value resulting from this study of 0.963. There was an increase in the value of b of 0.425, which means that there has been an increase in rock brittleness in the study area.

Seismicity Index, Return Period and Earthquake Risk Level

From the results of data processing, the seismicity index for shallow earthquakes with a magnitude of 5.0 < M < 6.0 is obtained, ranging between 0.31553 and 0.03437 (table 4). As a comparison, the value of the seismicity index in previous research was 0.06 for an earthquake with a magnitude M > 5.0 in the Cianjur area and its surroundings (Suwandi et al., 2017).

The results of the return period calculation for shallow earthquakes can be seen in table 5.

Table 5. Magnitude and Return Period

Magnitude	Return Period (year)
θ (M ≥ 5.0)	3.17
θ (M ≥ 5.2)	4.94
θ (M ≥ 5.3)	6.16
θ (M ≥ 5.5)	9.6
θ (M ≥ 5.6)	11.99
θ (M ≥ 5.8)	18.67
θ (M ≥ 5.9)	23.3
θ (M ≥ 6.0)	29.1
θ (M ≥ 6.5)	88.12
θ (M ≥ 7.0)	267.38

The return period for shallow earthquakes with magnitude 5.0 < M < 6.0 is between 3.17 and 29.1 years (table 5). In previous studies, the return period for shallow earthquakes with magnitude M > 5.0 was obtained for 17 years (Suwandi et al., 2017).

Judging from the results of data processing, in general it can be seen that the seismicity index in the Cianjur area and its surroundings is relatively large and the return period is small. This shows that the Cianjur area and its surroundings are areas that have a high risk of earthquakes.

From the results of calculations using the empirical equation, it can be seen the level of risk of shallow earthquakes for a certain time period in Cianjur and surrounding areas as shown in table 6.

Table 6. Period and Seismic Risk

Period	Seismic Risk (%)		
	M>5.0	M>6.0	M>7.0
10	95.74	20.09	3.67
20	99.82	49.7	7.21
30	100	64.34	10.61
40	100	74.71	13.89
50	100	82.07	17.06
60	100	87.29	20.1
70	100	90.98	23.03
80	100	93.61	25.86
90	100	95.47	28.58
100	100	96.78	31.2

From the table 6, it can be shown that for shallow earthquakes, the risk level of recurrence with a magnitude of 5.0 < M < 6.0 in the next 10 years is between 95.74% and 20.09%. Meanwhile, for the next 20 years, the risk level for a shallow earthquake with a magnitude of 5.0 < M < 6.0 is between 99.82% and 49.7%.

In previous research, seismicity index values were obtained at 0.05, a return period of 19 years, and the risk level for shallow earthquakes in the Cianjur area and its surroundings was between 41.8% to 99.6% (Zera, 2014). There are differences in seismicity index, return periods, and risk levels between the results of previous research and the results of this research.

This is due to differences in the earthquake data used in this study with a smaller area. In previous studies, the data were spread over the West Java region wider.

Conclusion

From the results of the analysis and discussion, a conclusion can be drawn that the destructive earthquake that occurred in the Cianjur area and its surroundings originated from the Cimandiri fault with a magnitude of $5.0 < M < 6.0$ and a shallow depth (0-60km). Much damage occurred in buildings that were not designed as earthquake resistant buildings. With large seismicity index values, a small return period, and a large risk level, the Cianjur area and its surroundings are areas that are prone to earthquake disasters. By knowing the parameters of the seismicity index, return period and risk level, it can be used as information to develop a more well-planned earthquake disaster mitigation program.

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Conflicts of interest

The authors declare that there are no conflicts of interest.

References

Ariyanto, P., Gustono, S. T., Margiono, R., Ricaksono, A. L., Affan, M. F., Marsono, A., ... & Suardi, I. (2023). Identifikasi Sesar Cimandiri Segmen Cidadap Menggunakan Metode Geolistrik Resistivitas Konfigurasi Dipole – Dipole dan Schlumberger. Wahana Fisika, 8(1), 48-63.

Badan Meteorologi, Klimatologi, dan Geofisika (BMKG). (2022). Katalog Gempa Bumi Signifikan dan Merusak tahun 1821 – 2018. Jakarta.

Gutenberg, B., Richter, C.F., 1954, Earthquake Magnitüde, Intensity, Energy and Acceleration, Bull. Seism. Soc. Am., 32 (3), 162-191.

Irsyam, M., Dangkua, D. T., Hendriyawan, H., Hoedajanto, D., Hutapea, B. M., Kertapati, E. K., ... & Petersen, M. D. (2008). Proposed seismic hazard maps of Sumatra and Java islands and microzonation study of Jakarta city, Indonesia. *Journal of Earth System Science, 117*(S2), November 2008, 865–878.

Jumila, H., Sofyan, H., & Rahayu, L. (2019). Estimation of return period of the destructive earthquake in Aceh using the maximum likelihood method. *IOP Conference Series: Earth and Environmental Science, 273*, 012024.

Munandar, R. A., & Sulsaladin, R. (2022). Karakteristik Tektonik dan Periode Ulang Gempabumi pada Sesar Cimandiri Jawa Barat. *Buletin Meteorologi, Klimatologi, dan Geofisika, 3*(3), Mei 2022, 42-51.

Peter Welker , M .(1965). Statistical Analysis of Earthquakes Occurance in Japan. *Bulletin of IISEE , Vol . 2,1965 .*

Putra, R. R., Kyona, J., Ono, Y., & Parajuli, H. R. (2012). Seismic Hazard Analysis for Indonesia. *Journal of Disaster Science, 33*(2), 59-70.

Patrisia, D., Sailah, S., & Affandi, A. K. (2019). Analysis of seismicity level and return period of Bengkulu area earthquake from 1960-2017. *Journal of Physics: Conference Series, 1282*, 012053.

Pailoplee, S. (2017). Probabilities of Earthquake Occurrences along the Sumatra-Andaman Subduction Zone. *Open Geosciences, 9*, 53–60.

Supendi, P., Priyobudi, J., Jatnika, J., Sianipar, D., Ali, Y. H., Heryandoko, N., ... & Karnawati, D. (2022). Analisis Gempabumi Cianjur (Jawa Barat) Mw 5.6 Tanggal 21 November 2022.

Kelompok Kerja Sesar Aktif dan Katalog Gempabumi Badan Meteorologi, Klimatologi, dan Geofisika (BMKG), Jakarta 10720, Indonesia.

Sari, A. M., & Fakhrurrozi, A. (2020). Seismic Hazard Microzonation Based on Probability Seismic Hazard Analysis in Bandung Basin. Pusat Penelitian Geoteknologi, LIPI, Jl. Sangkuriang Bandung 40135.

Soehaimi, A., Saputra, S. E. A., Sopyan, Y., Tanjung, R. A., Komalasari, R., Setiawan, S. P. A., ... (2022). Seismic Hazard Microzonation of Tasikmalaya City, West Java Province, Indonesia. *Earth Sciences, 11*(4), 220-231.

Shrestha, N. (2019). Estimating the Probability of Earthquake Occurrence and Return Period Using Generalized Linear Models. *Journal of Geoscience and Environment Protection, 7*, 11-24.

Sutrisno, S., & Perdana, S. P. (2015). Penentuan Percepatan Tanah Maksimum di Daerah Jawa Barat menggunakan metode Atkinson Boore. *Jurnal Al'Fiziya, IX*(2), April 2015.

Sutrisno, & Budiono, A. (2021). The Application of Seismic Coefficient in Simple Earthquake-Resistant Houses. *Journal of Natural Science and Mathematic Research, 7*(2), 79-85.

Suwandi, E. A., Sari, I. L., & Waslaluddin. (2017). Analisis Percepatan Tanah Maksimum, Intensitas Maksimum Dan Periode Ulang Gempa Untuk Menentukan Tingkat Kerentanan Seismik di Jawa Barat. *Wahana Fisika, 2*(2), 12 – 30.

United States Geological Survey (USGS). (2023). Katalog Gempa Bumi dari United State of Geological Survey tahun 1973 – 2023.

Triyoso, W., Suwondo, A., Yudistira, T., & Sahara, D. P. (2020). Seismic Hazard Function (SHF) study of coastal sources of Sumatra Island: SHF evaluation of Padang and Bengkulu cities. *Geosciences Letters, 7*(2).

Yuliastuti, E. E. (2018). Gutenberg-Richter Recurrence Law Analysis of RDE Site at Serpong. In *Prosiding Seminar Nasional Infrastruktur Energi Nuklir 2018,* Yogyakarta, 25 Oktober 2018.

Zera, T. (2014). Menentukan Peluang dan Periode Ulang Gempa dengan Magnitude Tertentu Berdasarkan Model Guttenberg – Richter. *Spektra: Jurnal Fisika dan Aplikasinya, 15*(1), Mei 2014.