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Earthquake Hazard Analysis of National Vital Objects by Probabilistic Seismic Hazard Analysis Method in West Java

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National vital objects

ABSTRACT

The Probabilistic Seismic Hazard Analysis (PSHA) method was used to analyze the level of earthquake hazard in West Java Province, Indonesia, which is located between two active tectonic plates. This research integrates literature study, earthquake data collection, and data processing to explore the influence of megathrust, background, fault, and combine earthquake sources on local and national vital objects in the region, such as Pusdik Kopassus, Presidential Palace, Cirebon PLTU, Geothermal Power Plant, Peacekeeping Mission Center (PMPP TNI), PT. PINDAD, PT DAHANA SUBANG, PLM GUNUNG SAWAL, Walahar Dam, PT Indonesia Power UJP Jabar 2 Pelabuhan Ratu, which have important roles in critical infrastructure, defense, and national resilience. The analysis shows variations in maximum ground acceleration between 0.40 g to 1.00 g for background earthquake sources, and 0.00 g to 1.00 g for fault earthquake sources. The research also underscores the importance of mitigation efforts and proper planning to reduce the potential impact of earthquakes in West Java, taking into account the crucial role of national vital objects in maintaining the stability and sustainability of the region. The implications of these findings reinforce the urgency to improve coordination between stakeholders in building earthquake resilience at the local and national levels, and highlight the importance of hazard curve analysis on national vital objects to inform the future of the region.

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1. Introduction

Earthquakes are natural disasters that have the potential to damage and have a serious impact on human life and infrastructure. In Indonesia, especially West Java is one part of Indonesia that is prone to earthquake disasters because West Java is located between two active tectonic plates, namely the Indo-Australian Plate and the Eurasian Plate which forms the Sunda Arc system in the offshore area consisting of the Java trough, the Java ridge, and the arc-face basin as shown in Figure 1 [1].

The impact of these tectonic conditions has resulted in areas along the Sunda Arc becoming relatively earthquake-prone. Seismic activity in this region can cause significant damage to critical infrastructure, and threaten the safety and well-being of communities [3].

West Java Province is one of the provinces with a high level of vulnerability to earthquake hazards. This area is one of the most potential areas because it is the center of government such as the Presidential Palace, UN embassies, energy installations, defense industries, dams, and education. Concerns related to the durability and safety of buildings and structures against maximum earthquakes are not always caused by an increase in design earthquake loads alone. If the tendency for construction practices to be widely distributed throughout Indonesia is the main cause of the many earthquake-induced building collapses that characterize construction in West Java, then the problem at hand is very serious and requires a thorough and immediate analysis of solutions, treatments and prevention. Based on the description above, it is necessary to analyze seismic hazard in the West Java region on several vital local and national objects as a review of regulations that refer to a more representative method of making earthquake hazard maps considering that West Java has the potential for shaking, so that if there is a certain earthquake scenario, it will cause huge losses [4].

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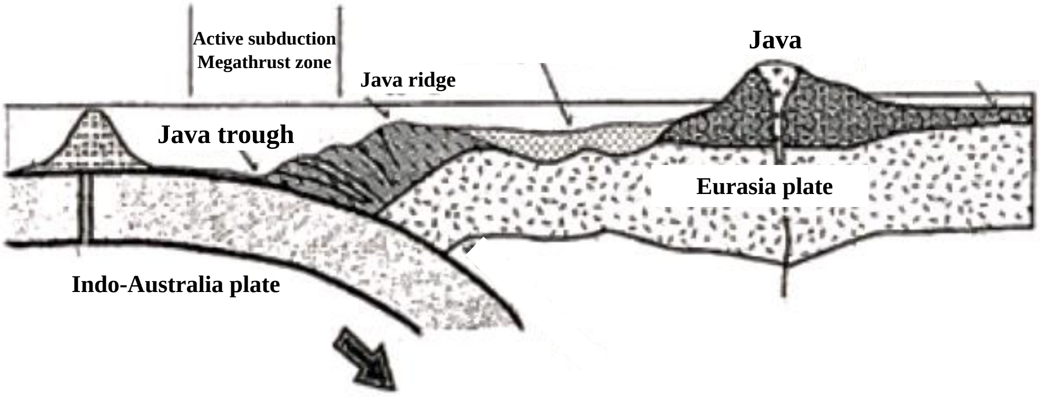

Figure 1. Geological cross section of Java Island [2]

Some researchers who have conducted research on earthquake hazard analysis in the West Java region include the following.

Achmed Shiddiq [5] conducted research on seismic hazard analysis with the Probability Seismic Hazard (PSHA) method at West Java International Airport in the Peak Ground Acceleration (PGA) zones of 0.1923 g and 0.3340 g.

Jimmy Nugraha, et. al. [3] conducted research on earthquake hazard analysis and isoseismal for the Java-Bali-NTB region. The results showed that areas in southern West Java experienced strong shaking around VII - VIII MMI (0.25 g - 0.3 g).

Satria Putra P [6] analyzed the calculation of Peak Ground Acceleration (PGA) in the West Java region. The results showed that the maximum acceleration based on the 1973 - 2009 earthquake case study ranged from 0.010648 - 0.160793 gal.

In recent decades, studies on seismic hazard analysis have progressed rapidly, especially with the use of the Probability Seismic Hazard (PSHA) method. Probabilistic Seismic Hazard Analysis (PSHA). PSHA was developed based on the total probability theory proposed by Cornell [7]. It is a scientific approach that considers the occurrence of earthquakes in a region by taking into account frequency, magnitude, and epicenter location. In the context of PSHA, the probabilistic aspect allows the identification of the level of risk and chance of earthquake occurrence at each location. Previous studies have contributed a lot to the science and use of earthquake hazards. However, they tend to focus on analyzing calculations on a regional or general scale, with few studies that specifically consider earthquake hazards on vital objects of local, national and international scale in West Java, which has diverse geological characteristics and population density [8]. The classification of 3 types of earthquake source zones can be seen in Table 1.

Table 1. Classification of 3 types of earthquake source zones

Earthquake Source Model	Description
Megathrust (Subduction)	A zone of earthquake occurrence that occurs near the boundary where an oceanic plate subducts beneath a continental plate. The source of subduction earthquakes is limited to a depth of 50 km.
Fault	earthquake event zones that occur on well-defined faults, including mechanism, slip rate, dip, fault length and location.
Background (gridded seismicity)	The earthquake source is not yet clearly known, but in that place there are several earthquake events. This earthquake source model is classified into two, namely shallow background (depth up to 50 km) and deep background (depth more than 50 km). The deep background earthquake source model itself is divided into four intervals, namely depths of 50-100 km, 100-150 km, 150-200 km and 200-300 km.

Seismic Hazard Analysis. The purpose of seismic hazard analysis is to provide a more definitive estimate of the intensity of an earthquake that may occur at a site. This can be done in a detailed manner (Deterministic Seismic Hazard Analysis) by considering certain predefined earthquake scenarios, or in a probabilistic manner (Probabilistic Seismic Hazard Analysis), which takes into account various possibilities such as magnitude, geographical location, and time of earthquake occurrence [9]-[12].

Habitual Return Model. The return time model is a model that describes the frequency distribution of earthquakes ranging from small to large ones originating from a particular earthquake source [13]. This model is used as a tool to analyze the level of earthquake activity in a region. The results of the habitual model are again reflected in the frequency distribution of the magnitude of the earthquakes that occur.

$$\log N_{(m)} = a - bM \quad (1)$$

with a, b as positive ril constants, $N_{(m)}$ as frequency of earthquake occurrence by magnitude $M \geq m$ per unit time.

Peak Magnitude and Rate of Movement. Peak magnitude is a representation of the magnitude of the largest earthquake ever recorded in history in a region, based on scientific research or geophysical calculations, and considering the tectonic characteristics and rock displacements in the region. Meanwhile, the slip rate describes the relative displacement speed between the earthquake source zone and other zones [14]. The magnitude and direction of the slip rate can be estimated using GPS survey methods.

Risk of Earthquake Occurrence. Earthquake risk is the probability of an earthquake with a certain intensity occurring during the lifetime of a building. The estimated value of earthquake risk can be expressed mathematically as Equation 2.

$$R_n = 1 - (1 - R_a)^n \quad (2)$$

where R_n is earthquake risk, R_a is year risk $1/T$. T is earthquake return period, n is useful life of the building.

Probabilistic Earthquake Hazard Analysis. The PSHA method was originally developed by Cornell, and later expanded by Merz and Cornell. Although the basic concept of this analysis remains unchanged, the model and calculation techniques have been continuously updated by McGuire R. K. This theory considers earthquake magnitude (M) and distance (R) as continuous independent random variables. In general, this total probability theory can be formulated as Equation 3.

$$P[I \geq i] = \iint_{r\,m}^{\infty} P[I \geq i | m \text{ and } r] f_M(m) f_R(r) dmdr \quad (3)$$

where f_M is magnitude distribution fuction, f_R is hypocenter distance distribution function, P [$I \geq i | m$ and r] is conditional probability of intensity I exceeding value i at a given location for an earthquake event with magnitude M and hypocenter distance R.

Maximum Ground Acceleration. Peak Ground Acceleration (PGA) refers to the maximum value of ground acceleration that occurs during an earthquake, which is usually measured using a device called an accelerograph. PGA calculations are generally made using Equation 4.

$$PGA = A_{max} \, x \, CF \quad (4)$$

PGA stands for Peak Ground Acceleration which indicates the maximum ground acceleration. A_{max} refers to the maximum amplitude, while CF is the conversion factor, which is a constant used to convert one unit counts into earthquake wave amplitude.

Although there have been several attempts to analyze earthquake hazards in West Java, there is a lack of indepth understanding of the potential earthquake risks in the province. Therefore, this study aims to fill this gap by creating an earthquake hazard using the Probability Seismic Hazard (PSHA) method that is more detailed and focused on the province of West Java, taking into account geological factors, topography and vital infrastructure. Thus, mitigation and planning measures can be taken more precisely and efficiently. By understanding earthquake hazard analysis using the PSHA method, it is expected to improve preparedness and response to potential earthquakes in West Java and maintain the resilience of vital objects against these threats [9].

2. Methods

The location in the study took the West Java area with coordinates 5.500 - 7.500 S and 104.480 E. Figure 2 shows the location of the research location point.

This research utilized secondary data from Indonesia Geospatial related to earthquakes in certain areas, which were obtained from Indonesia's geospatial database and selected according to the research criteria. The analysis was conducted using the Probabilistic Seismic Hazard Analysis (PSHA) method due to its ability to produce accurate estimates of earthquake hazard levels by considering the probability of earthquake occurrence, location and frequency of occurrence [15]. This method was chosen because it is in line with the research objectives and provides a comprehensive picture of the earthquake hazard in the West Java region.

Figure 2. Research Location

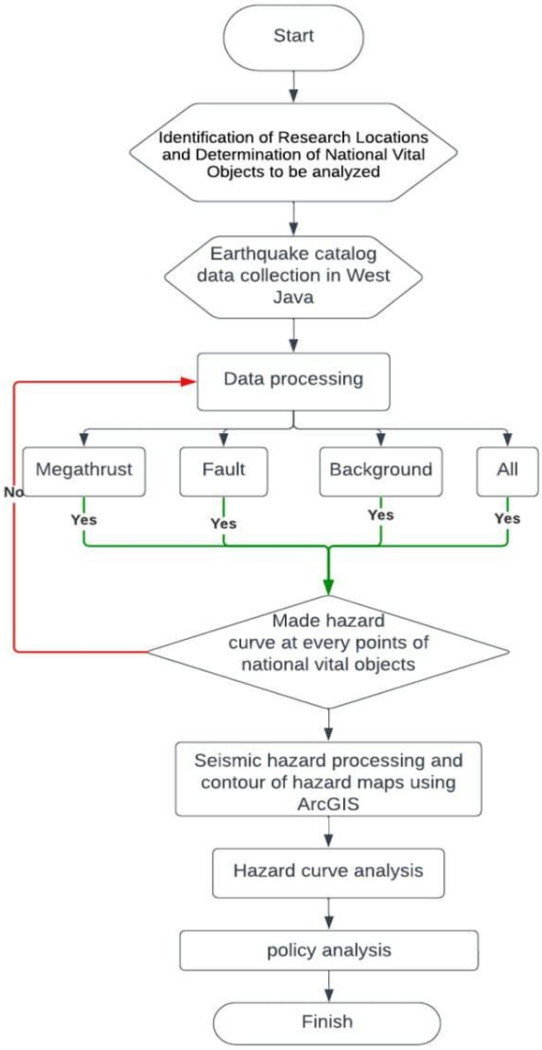

Figure 3. Research Flowchart

The initial stage of the research involved a literature study to understand relevant theories and methods, especially those related to the Probability Seismic Hazard Analysis (PSHA) method [17]. The next step was to determine the research location and collect earthquake catalog data in the area. After that, data processing is carried out to obtain the values needed in the analysis. The next step is to map the earthquake hazard based on four predefined workflows: Megathrust, Fault, Background and Combine Source (ALL). The final stage involved mapping the distribution of earthquake hazards using the ArcGIS application, utilizing data from the PSHA analysis such as Peak Ground Acceleration (PGA) values.

Each workflow was used as the basis for creating a Hazard Curve. The results of the mapping are 10 curves that show the pattern of earthquake hazards where the probability of earthquake events to the level of damage that may occur in 500 years, 1,000 years, 2,500 years, 5,000 years, and 10,000 years at each point of the location of vital objects that have been determined.

Hazard Curve results are analyzed to understand the patterns and characteristics of earthquake hazards at each vital object location so that this information becomes important for decision-making in development planning and earthquake disaster risk mitigation at each vital object location in the future can be seen in Figure 3.

3. Result and Discussion

The Megathrust or subduction-induced earthquake hazard map displays an analysis of the acceleration ranges across the site, shown in Figure 4, with the highest value found at PT Indonesia Power UJP Jabar 2 and the lowest at PLTU Cirebon. The range of maximum ground acceleration values varies between 0.10 and 0.50g. Previous studies have shown that subduction earthquake sources have significant impacts at considerable distances. This indicates that the observed acceleration patterns may be influenced by the characteristics of the Megathrust earthquake source itself, such as the depth and length of the fault. Further studies may be required to compare these results with other studies and understand the causes of the observed acceleration patterns in more depth.

The Fault-induced Earthquake Hazard Map illustrates the range of accelerations at various locations as shown in Figure 5, with the highest values recorded at PT Indonesia Power UJP Jabar 2, PT PINDAD, and Pusdik Kopassus, while the lowest values were recorded at Walahar Dam. The range of maximum ground acceleration values at bedrock ranges from 0.00 to 1.00g. Previous research has shown that the faults used as earthquake sources in this study are well identified and provide significant hazard values, such as the Cimandiri, Lasem, Opak, and Lembang faults. The research conducted emphasizes that the same faults still have a significant impact in causing earthquakes, including the Cimandiri, Lembang, and Rajamandala Faults. This shows consistency in the influence of Fault sources on earthquake hazard in the region, albeit with variations in acceleration values occurring at specific locations. This study strengthens the understanding of the contribution of these faults to earthquake hazard

The Background seismic hazard map displays the range of acceleration at various locations, with the highest value recorded at PT Indonesia Power UJP Jabar 2, while the lowest value was recorded at PLTU Cirebon. The range of maximum ground acceleration values at bedrock ranges from 0.40 to 1.00 g as shown in Figure 6. The results of previous studies indicate that the high acceleration values are most likely due to the presence of faults that have not been properly identified or have been identified but the parameters required in the PSHA input are incomplete. The current study confirms that the acceleration range remains relevant, indicating that background earthquake sources still have the potential to cause significant acceleration within the specified timeframe. Nonetheless, the presence of the lowest value at PLTU Cirebon indicates variations in the impact of background earthquakes at different locations, which may be influenced by local geological factors and the characteristics of the earthquake source.

The earthquake hazard map resulting from the Combine Source (ALL) displays the range of accelerations at various locations, with the highest values found at PT Indonesia Power UJP Jabar 2, while the lowest values were recorded at Walahar Dam, PT Dahana, and PLTU Cirebon. The range of maximum ground acceleration values in the bedrock of the West Java region from the combination of the three earthquake sources ranges from 0.40 to 1.50 g, as shown in Figure 7. Previous studies have identified that areas with high acceleration are those that are close to faulting and subduction earthquake sources, such as the West Java region. The current study confirms these findings and adds that the areas with significant accelerations are mainly concentrated in Sukabumi District and City. This suggests that the observed acceleration patterns are still consistent with the influence of faulting and subduction earthquake sources, with variations that may be influenced by local geological and geographical factors. These findings provide deeper insights into the distribution of earthquake hazards in the West Java region.

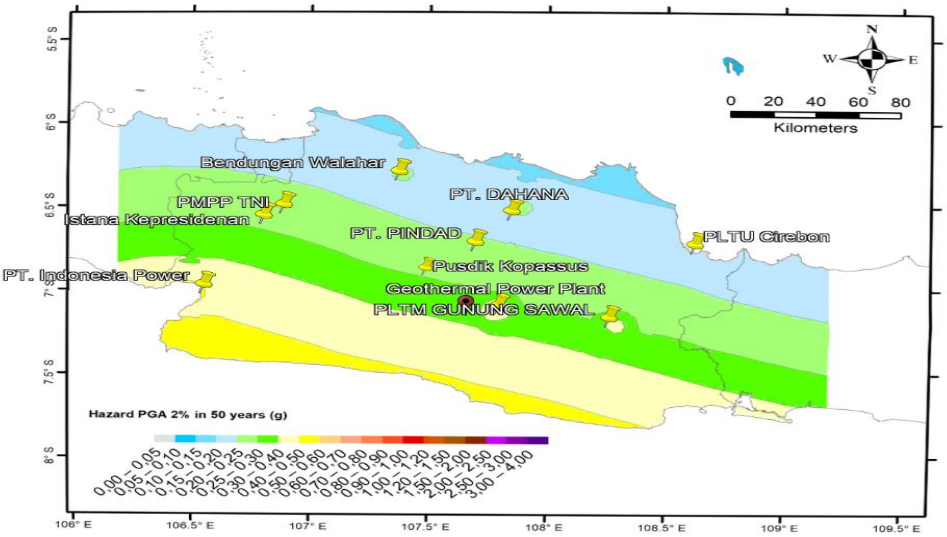

Figure 4. Earthquake Hazard Map due to Megathrust

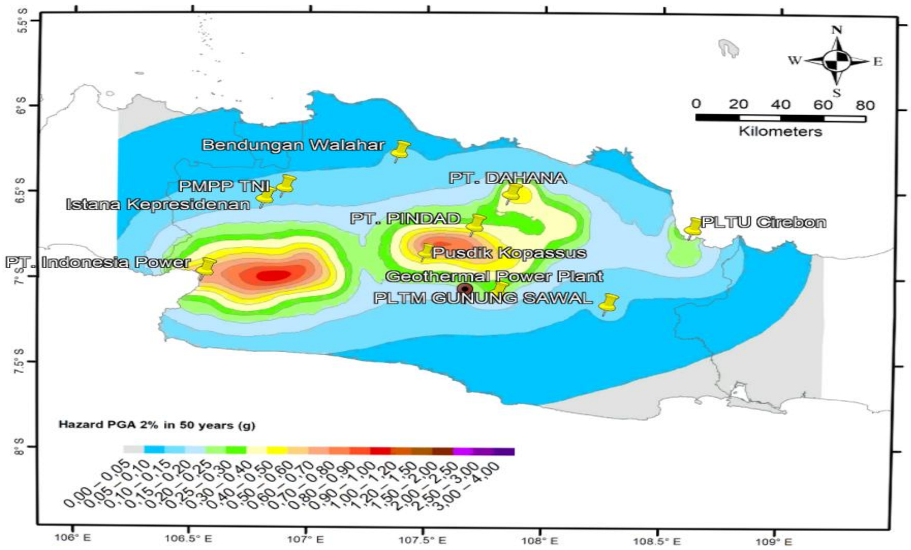

Figure 5. Earthquake Hazard Map due to Fault

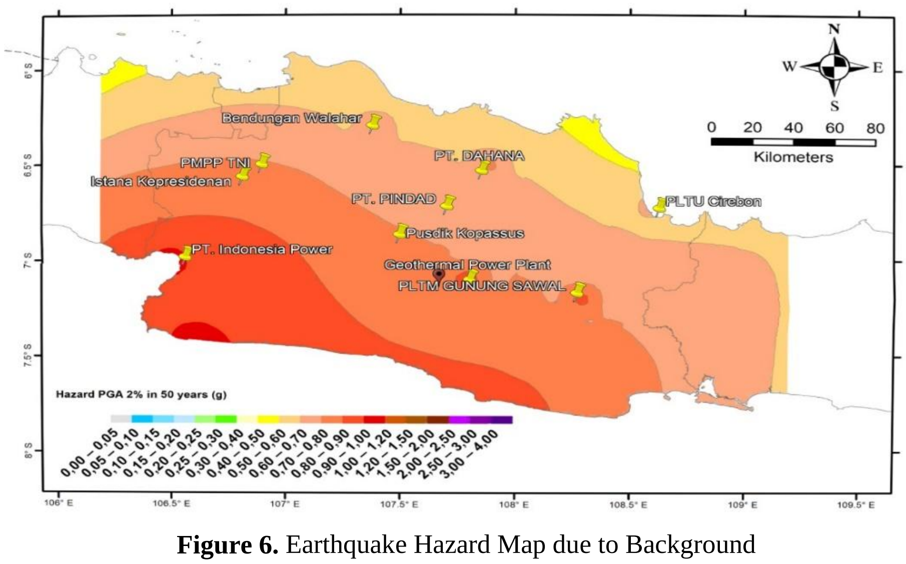

Figure 6. Earthquake Hazard Map due to Background

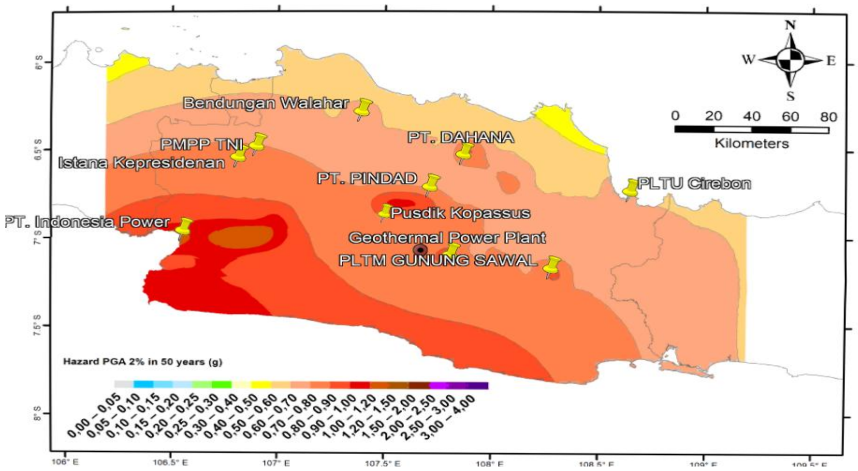

Figure 7. Earthquake Hazard Map due to Combine Source (All)

Earthquake Hazard Curve. To determine the contribution of each earthquake source to the earthquake hazard at several national vital objects. The results of the Probabilistic Seismic Hazard Analysis (PSHA) are presented in the form of earthquake hazard curves. The earthquake hazard curve is the relationship between the annual rate of exceedance and the magnitude of the earthquake hazard that occurs.

For 6 national vital objects, consisting of: Cirebon PLTU, Geothermal Power Plant, PT DAHANA SUBANG, PLM GUNUNG SAWAL, Walahar Dam, and PT Indonesia Power UJP Jabar 2 UJP 2 UJP 2 Pelabuhan Ratu using a 5000-year return period, because the 6 national vital objects are places that are required for sturdy buildings. The following are the hazard curves of several national vital objects under PGA conditions for a probability of exceeding 2% in 50 years.

3.1 Pusdik Kopassus

The earthquake source that has the greatest hazard to the Kopassus training center is the Background earthquake source. Earthquakes often occur at depths of 0 - 300 m as shown in Figure 8.

3.2 Presidential Palace

The earthquake source that has the greatest hazard to the presidential palace is the Background earthquake source (0 - 300 m) in Figure 9.

3.3 PLTU Cirebon

The earthquake source that has the greatest hazard for the Cirebon PLTU is the Background earthquake source (0-300 m) as shown in Figure 10.

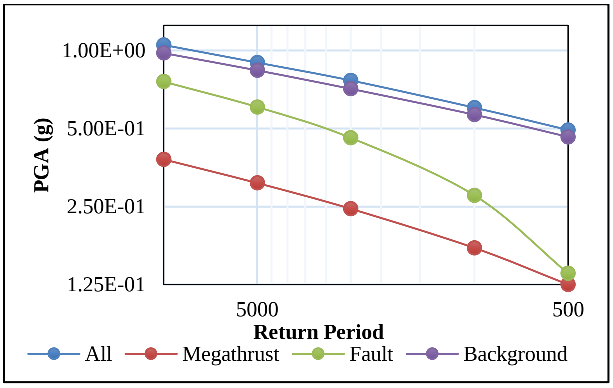

Figure 8. Pusdik Kopassus Hazard Curve

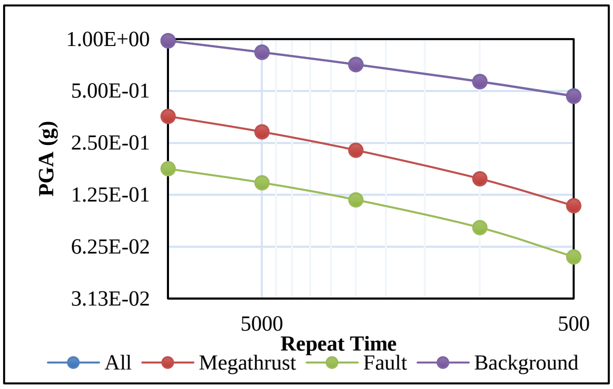

Figure 9. Presidential Palace Hazard Curve

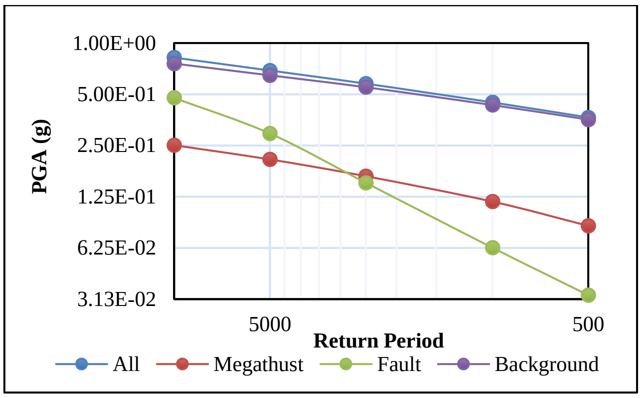

Figure 10. PLTU Cirebon Hazard Curve

3.4 Geothermal Power Plant

The earthquake source that has the greatest hazard for Geothermal Power Plant is the Background earthquake source. Earthquakes often occur at depths of 0 - 300 m as shown in Figure 11.

3.5 TNI Peacekeeping Mission Center (PMPP TNI)

The earthquake source that has the greatest hazard to the TNI Peacekeeping Mission Center (PMPP TNI) is the Background earthquake source (0 - 300 m) in Figure 12.

3.5 PT. Pindad

The earthquake source that has the greatest hazard for PT PINDAD is the Background earthquake source. Earthquakes often occur at a depth of 0 - 300 m as shown in Figure 13.

3.6 PT. Dahana Subang

The earthquake source that has the greatest hazard for PT DAHANA SUBANG is the Background earthquake source (0 - 300 m) in Figure 14.

3.7 PLM Gunung Sawal

The earthquake source that has the greatest hazard to the PLM GUNUNG SAWAL is the Background earthquake source. Earthquakes often occur at depths of 0 - 300 m as shown in Figure 15.

3.8 Walahar Weir

The earthquake source that has the greatest hazard for Walahar Dam is the Background earthquake source (0 - 300 m) in Figure 16.

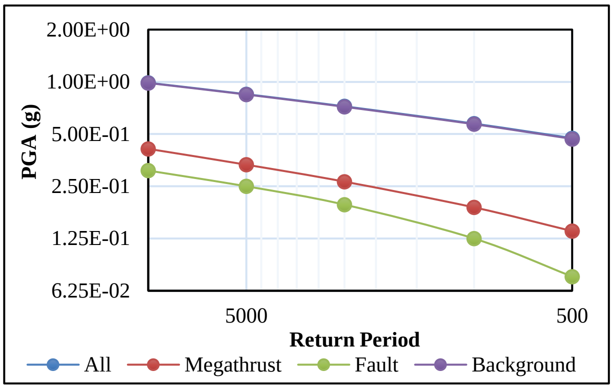

Figure 11. Geothermal Power Plant Hazard Curve

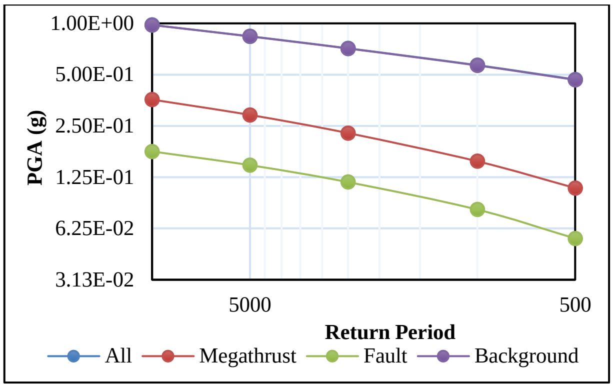

Figure 12. PMPP TNI Hazard Curve

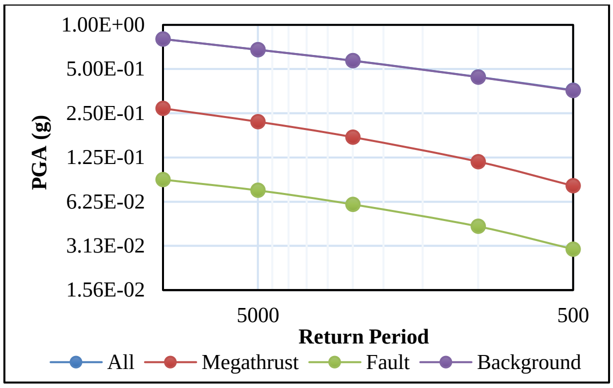

Figure 13. PT. Pindad Hazard Curve

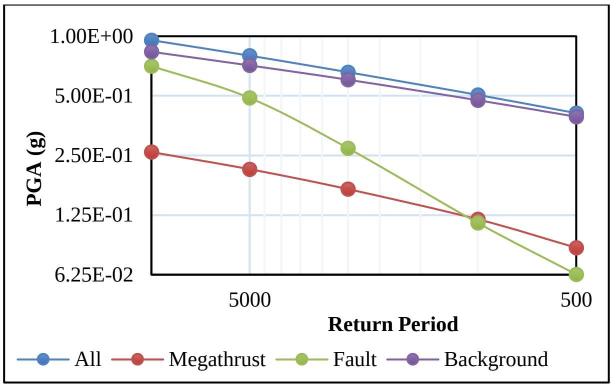

Figure 14. PT. Dahana Subang Hazard Curve

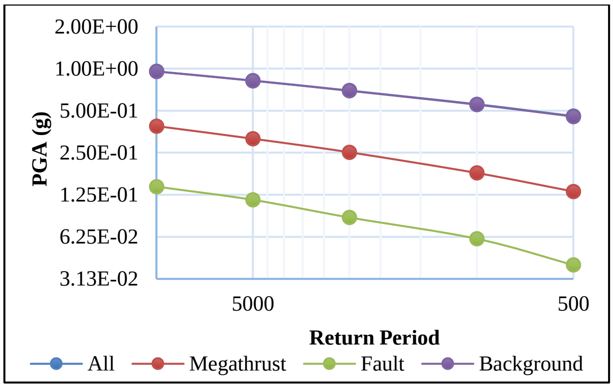

Figure 15. PTM Gunung Sawal Hazard Curve

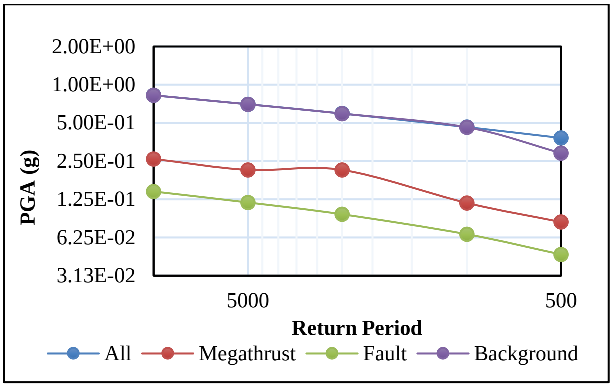

Figure 16. Walahar Weir Hazard Curve

3.9 PT Indonesia Power UJP Jabar 2 Pelabuhan Ratu

The earthquake source that has the greatest hazard to PT Indonesia Power UJP Jabar 2 Pelabuhan Ratu is the Background earthquake source. Earthquakes often occur at a depth of 0 - 300 m as shown in Figure 17.

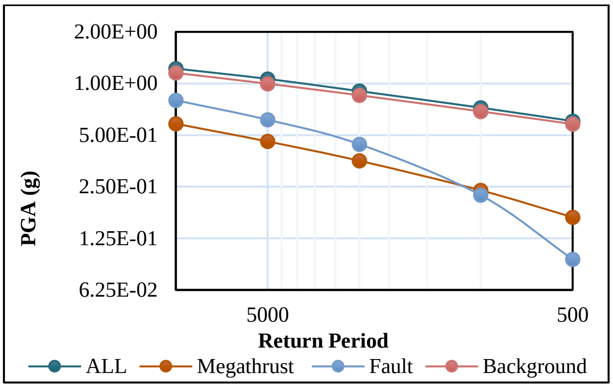

Figure 17. PT Indonesia Power UJP JABAR 2 Hazard Curve

4. Conclusion

From the results of the earthquake hazard curve analysis using the Probabilistic Seismic Hazard Analysis (PSHA) method in West Java province, it can be concluded that the background earthquake source is very influential on several vital object points in West Java, one of which is PT Indonesia Power UJP JABAR 2 Pelabuhan Ratu. The value of maximum ground acceleration in the bedrock of West Java province in the background earthquake under Peak Ground Acceleration (PGA) conditions for a probability of exceeding 2% in 50 years ranges from 0.40g - 1.00g. In addition, fault earthquake sources also affect the hazard at several vital object points such as PT Indonesia Power UJP Jabar 2 Pelabuhan Ratu, PT PINDAD, Pusdik Kopassus, and PT DAHANA. Given that these vital object points are located very close to the fault earthquake source. The maximum ground acceleration value in the bedrock of West Java province in the fault earthquake under Peak Ground Acceleration (PGA) conditions for a probability of exceeding 2% in 50 years ranges from 0.00g - 1.00g. Based on the results of these studies, it is noted that there are many places located in areas with high levels of earthquake hazard. To reduce the risk and mitigate the potential impact of earthquakes, it is recommended to take measures that are expected to increase the readiness and resilience to earthquakes in the West Java region, especially in several national vital objects, so as to reduce the potential for human and material losses.

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