KPJ 8(3) (2024)

KAPPA JOURNAL
Physics & Physics Education

https://e-journal.hamzanwadi.ac.id/index.php/kpj/index

Estimation of Earthquake Intensity and Peak Ground Acceleration in West Java Using the MC Guire and the Lin & Lee Method

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Received: 09 November 2024
Revised: 30 November 2024
Accepted: 04 December 2024

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DOI:
https://doi.org/10.29408/kpj.v8i3.28095

Abstract: West Java province was in a subduction zone and fault zone (slip fault), which caused earthquakes. Therefore, it was necessary to research estimates of maximum ground acceleration in West Java to mitigate earthquake disasters. This research also aimed to determine the value of ground acceleration and earthquake intensity and to determine the distribution map using the McGuire method and the Lin & Lee method. The data used were earthquake data for 1950-2023 with a magnitude > 5 SR. From processing this data, the maximum ground acceleration value in West Java ranged between 10.14722-195.3540 gal, and the maximum intensity value was IV-VI MMI using the Mc Guire method. Meanwhile, for the Lin & Lee method, it ranged between 6.6512 to 49.24599 gal. Of the two methods, the largest maximum ground acceleration value was located in Cianjur Regency, which was due to its proximity to the Cimandiri fault and the geological conditions in the area.

Keywords: Earthquake; Maximum Ground Acceleration (PGA); Intensity (MMI)

Introduction

Java Island is situated between the really structural plates, particularly in the southern piece of Java Island. Because of the gathering of these plates, a subduction zone is framed, to be specific the gathering between the Eurasian plate which is toward the north, and the Indo-Australian plate which is toward the south. The Indo-Australian plate moves 60-70 mm per year along with the Eurasian plate (Newcomb & Mccan, 1987). In addition to being in the subduction zone, the West Java region also has fault zones (slip faults) below the surface, including the Cimandiri fault, Baribis fault, and Lembang fault (Sunardi et al, 2023). This makes the West Java locale a complicated district since there are subduction zones and shortcoming zones that can cause quakes (F. Muttaqy et al, 2020). A tremor is an unexpected arrival of seismic wave energy. This energy discharge is brought about by the distortion of structural plates that happen in the world's outside, causing misfortune, harm, and even death toll (Alfadilah et al, 2022). The cycle by which enormous and disastrous tremors emerge should be perceived considering the neighborhood structural circumstances and the degree of seismic movement (Raharjo, 2016).

The Meteorology, Climatology, and Geophysics Agency (BMKG) says that there have been several powerful and destructive earthquakes in the West Java region. One of these earthquakes was in Tasikmalaya on September 2, 2009, with a magnitude of 7.3 SR and 48 deaths. Then the earthquake that occurred in Pangandaran on July 17, 2009, this earthquake in Pangandaran caused a tsunami, resulting in sea waves

How to Cite:
Silvianis, R., Syafriani, S., Dwiridal, L., & Zulhendra, Z. (2024). Estimation of Earthquake Intensity and Peak Ground Acceleration in West Java Using the MC Guire and the Lin & Lee Method**.** *Kappa Journal, 8*(3), 331-337. https://doi.org/10.29408/kpj.v8i3.28095

that hit houses, restaurants, and hotels in the area around Pangandaran (Setyonegoro,2018). One of the parameters obtained when an earthquake occurs is ground acceleration (Dwi & Sabarani,2018). The ground acceleration chosen to be able to measure the strength of ground movement and be the starting point for initiating emergency protocols in an area due to an earthquake is the maximum ground acceleration (Wang et al, 2023). The maximum value of a region's ground acceleration caused by earthquake vibrations over a specific time period is known as maximum ground acceleration (Astuti et al, 2023). Maximum land value acceleration can be determined in two ways, namely using an accelerograph or through empirical calculations using earthquake data such as using the Mc Guire, Lin & Lee, Donovan formula and other empirical formulas (Rohman et al, 2022). The maximum ground acceleration value will vary with each earthquake. This depends on many factors, namely the distance of the epicenter, hypocenter, magnitude, geological conditions, and earthquake fault characteristics (Hason et al, 2021)

An important parameter for describing the level of earthquake risk in a region is the peak ground acceleration caused by an earthquake (Pratiwi et al, 2024). The more prominent the PGA esteem coming about because of a quake, the higher the power of the seismic tremor felt (Laksana, 2023). There has been extensive research on estimating maximum ground acceleration in West Java using various methods. For example, previous research analyzed peak ground acceleration using the Donovan and Matuscha methods based on secondary data from the USGS (1974-2016). However, this research did not use vs30 data, so the geological conditions in the West Java region could not be detailed. Additionally, there has been no research in West Java using data up to 2023, making it necessary to update the data to provide more accurate information (Suwandi et al, 2017). Furthermore, research conducted in Padang City determined the maximum ground acceleration using the Lin and Lee method based on data from 1963-2018. This research produced the highest ground acceleration value in Nanggalo and demonstrated that this method is effective in subduction zones (Raharjo,2022). Based on previous research, the researcher took the Mc. Guire method and the Lin&Lee method, the following is the empirical formulation used in this research (Douglas,2018).

The first empirical formula is the Mc. Guire Formula which can be used to determine the peak value of ground acceleration using the surface wave size. The formula is as follows (Mc Guire,1974):

$$a: 472{,}3 \times 10^{0{,}27 \times Ms} \times (R+25)^{-1{,}301} \quad (1)$$

Where, the ground acceleration value, symbolized by a, is measured in units of cm/s². The surface magnitude of an earthquake is indicated by Ms, the hypocenter distance is denoted as R and measured in kilometers, and H represents the depth of the earthquake in kilometers.

Based on the tectonics of the island of Java, Mc Guire's empirical formulation is by the conditions of the Java fault. The reason for this is that the formula is used to figure out what the PGA value was after the earthquake in Southern California, specifically on the San Andreas fault, which was caused by that earthquake. The Java fault shares many of the same characteristics as the San Andreas fault (Pawirodikmo,2012).

The second empirical formula is the Lin & Lee formula which can determine the value of ground acceleration using the moment magnitude. The formula is as follows (Hwang et al, 2004).

$$\text{Ln (PGA)}: C_1 + C_2 M + C_3 \ln(R + C_4\, e^{C_5 M})\, C_6 H + C_7 Z_t \quad (2)$$

Where Ln (PGA) represents the peak value of ground acceleration (cm/s²), with M represents the earthquake magnitude, R represents the hypocenter distance (km), H represents the depth of the source (km), and Zt represents the type of subduction. earthquakes, where Zt=0 represents interface subduction earthquakes and Zt=1 represents intraslab subduction earthquakes.

Lin & Lee's empirical formula is used to model subduction earthquake sources. Previous research has focused on understanding the attenuation characteristics of ground motion from subduction zone earthquakes in northeastern Taiwan and on determining suitable damping equations for these earthquakes by considering specific regional seismic characteristics. Based on geological conditions, the northeastern region of Taiwan is quite similar to the geological conditions in West Java.

The resulting peak value of ground acceleration can be used for disaster mitigation and spatial planning considerations. Complex conditions that influence PGA values in earthquakes of the same magnitude can produce different results, many earthquakes produce PGA values that are much greater than earthquakes with larger magnitudes (Irwansyah & Winarko et al, 2015). Mitigation needs to be carried out in anticipation so that casualties and material losses due to earthquakes can be reduced. Earthquake mitigation efforts that can be carried out to prevent casualties and damage to infrastructure due to the impact of earthquakes are by monitoring earthquake events and mapping active faults. The benefit of active fault mapping is to estimate the magnitude of earthquakes in an area. The longer the fault segment, the greater the magnitude that will occur. Apart from that, active fault mapping can be used to design earthquake-resistant buildings so that it can reduce earthquake victims. This can be done by providing outreach to people who live in earthquake-prone areas.

Method

This study is a descriptive research utilizing secondary data, specifically earthquake data from the United States Geological Survey (USGS) catalog covering the period from 1950 to 2023. This research examines the maximum ground acceleration values and earthquake intensity in West Java to determine areas that are vulnerable to earthquake damage in the West Java region. The parameters used in this research are latitude, longitude, depth, and earthquake magnitude. The earthquake data used for this study includes events with a magnitude of 5 SR and a depth of ≤ 70 km for McGuire's empirical formulation, and 44 ≤ 161 km for Lin & Lee's empirical formulation. The data pertains to earthquakes in West Java Province, with coordinates ranging from 5°50' S to 7°50' S and 104°48' E to 108°48' E. The data processing steps to determine the peak ground acceleration and earthquake intensity are as follows.

The first, calculate the distance between the earthquake epicenter coordinates and each coordinate point in the calculation area to determine the epicenter distance (D) using equation (3).

$$D^2 = (X_2 - X_1)^2 + (Y_2 - Y_1)^2 \quad (3)$$

Where D represents the distance from the epicenter to the earthquake recording station, with X_2 being the latitude of the recording station, X_1 the latitude of the epicenter, Y_2 the longitude of the recording station, and Y_1 the longitude of the epicenter. All measurements for D, X_2, X_1, Y_2, and Y_1 are in degrees (°). To convert the epicenter distance to kilometers, note that 1 degree of latitude is approximately equal to 111.3 km.

secondly, Determine the distance from the earthquake hypocenter (R) to each point within the estimation area. This hypocenter distance (R) can be calculated using Condition (4). The epicenter distance obtained must be converted to kilometers; for this conversion, 1 degree of latitude is approximately equal to 111.3 km (4).

$$R^2 = D^2 + H^2 \quad (4)$$

Where R represents the distance from the earthquake hypocenter (km), D denotes the distance from the quake focal point (km), and H is the depth of the earthquake (km). Once these parameters are obtained, their values are substituted into conditions (1) and (2). This process is used to determine the peak values of ground acceleration and earthquake intensity based on historical earthquake data from West Java Province. The research area is structured as a grid with a spacing of 0.10, as illustrated in Figure 1.

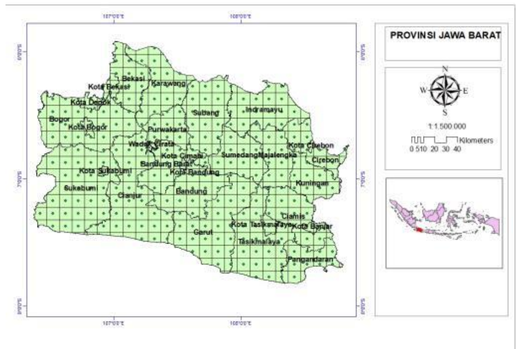

Figure 1. Measurement Point Maps For Data Processing Using the Mc Guire Method and the Lin & Lee Method

Based on Figure 1, measurement points were collected using the ArcGIS application at intervals of 0.10, resulting in a total of 501 measurement points across West Java. The third step involves analyzing and creating distribution maps with these two methods. The maximum ground acceleration value is crucial for assessing earthquake risk and should be considered during the development planning phase. Consequently, this value can be used to inform earthquake disaster mitigation efforts, particularly for West Java, in the construction of earthquake-resistant facilities and infrastructure.

Result and Discussion

The findings of this research include peak ground acceleration values derived from secondary earthquake data obtained from the USGS. Specifically, the study analyzed 10 earthquake records for depths less than 70 km and 41 records for depths ranging from 44 to 161 km, covering the period from 1950 to 2023. The earthquake distribution map can be shown in Figure 2.

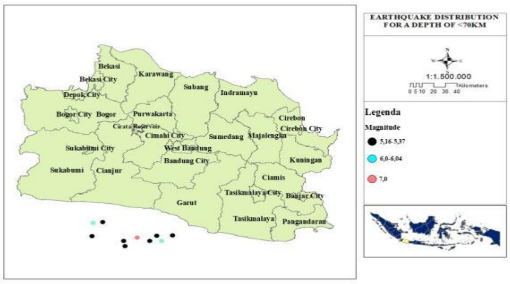

Figure 2. (a) Earthquake Distribution Map Based on Depth Data < 70km

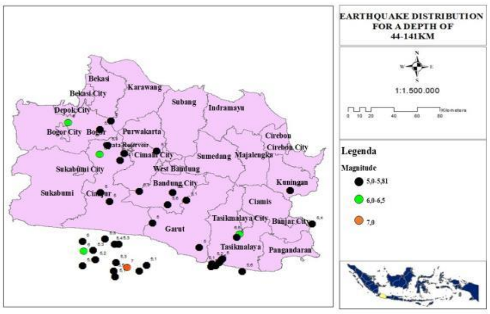

Figure 2. (b) Earthquake Distribution Map Based on Depth Data 44-160 km

Based on Figures 2(a) and 2(b) reveal that West Java Province has recorded 10 earthquake events with depths less than 70 km and 41 events with depths ranging from 44 -161 km. This data indicates that West Java experiences a relatively high level of seismic activity. The earthquake distribution map allows for the determination of maximum ground acceleration values for the West Java region using the McGuire and Lin & Lee formulas. According to the McGuire formula, the PGA values range from 10.14gal -195.20 gal, as shown in Table 1 below.

Table 1. Peak Ground Acceleration and Maximum Intensity Scale Using Mc Guire Method

Regency/City	Peak Ground Acceleration (gal)	Earthquake Intensity (MMI)
Bandung Regency	82,13-151,41	V-VI
Bandung Barat Regency	68,84-129,09	V-VI
Bekasi Regency	20,59-37,14	IV
Bogor Regency	29,86-66,69	IV-V
Ciamis Regency	41,11-59,36	V
Cianjur Regency	59,24-195,20	V-VII
Cirebon Regency	20,67-32,36	IV
Garut Regency	73,86-190,26	V-VII
Indramayu Regency	20,77-40,93	IV-V
Karawang Regency	20,91-52,53	IV-V
Kuningan Regency	26,84-43,179	IV-V
Majalengka Regency	32,40-51,15	IV-V
Pangandaran Regency	36,20-61,57	V
Purwakarta Regency	43,14-62,18	V
Subang Regency	26,98-64,66	IV-V
Sukabumi Regency	24,21-186,29	IV-VII
Sumedang Regency	47,37-87,64	V
Tasikmalaya Regency	31,59-121,74	IV-VI
Bandung City	81.90	V
Banjar City	39,39-46,06	V
Bekasi City	30,05-30,20	IV
Bogor City	45.23	V
Cimahi City	86.35	V
Cirebon City	10,14-28.90	II-IV
Depok City	31,73-33,47	IV
Sukabumi City	93.59	VI
Tasikmalaya City	75.53	V

Based on Table 1 the maximum ground acceleration value and the highest earthquake intensity are located in Cianjur District. The maximum ground acceleration value obtained was 59.24 gal -195,20 gal, with an earthquake intensity of V-VII MMI. The minimum ground acceleration value and lowest earthquake intensity were found in Cirebon City, with a value of 10,14 gal - 28.90 gal and an earthquake intensity of III-IV MMI.

Based on the data obtained, a map of maximum ground acceleration and earthquake intensity was produced, as shown in Figure 3.

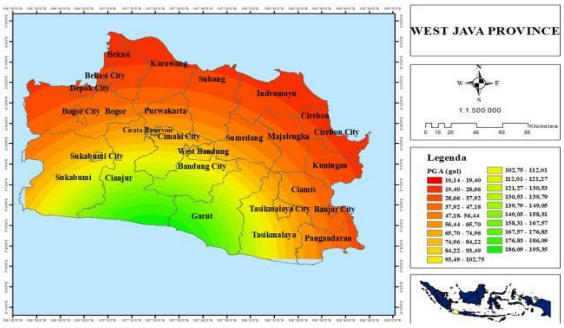

Figure 3. (a) Peak Ground Acceleration Map Using the Mc Guire Method

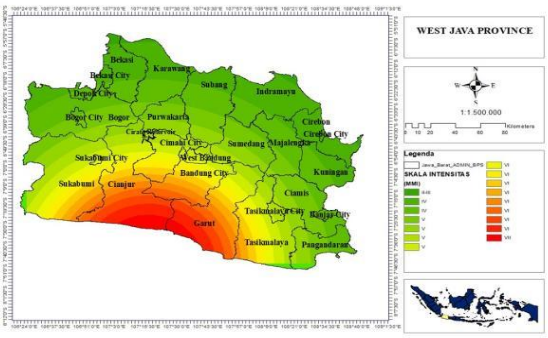

Figure 3. (b) Intesity Scale Map Using the Mc Guire Method

Based on Figures 3(a) and 3(b) indicate that Cianjur Regency has the highest maximum ground acceleration value, attributed to its proximity to the earthquake epicenter. Additionally, Cianjur Regency is situated within the Cimandiri Fault zone, an active fault in West Java, which contributes to the high acceleration values. Conversely, the lowest values were recorded in Cirebon City, which is located far from the earthquake epicenter and is in a region with relatively few faults in West Java.

The peak ground acceleration values calculated using the Lin & Lee formula are detailed in Table 2.

Table 2. Peak Ground Acceleration and Maximum Intensity Scale Using Lin& Lee Method

Regency/City	Peak Ground Acceleration (gal)	Earthquake Intensity (MMI)
Bandung Regency	46,44-100,01	V-VI
Bandung Barat Regency	36,89-82,29	IV-V
Bekasi Regency	7,11-15,59	II-III
Bogor Regency	10,89-35,38	II-IV
Ciamis Regency	18,51-26,84	IV
Cianjur Regency	30,25-135,31	IV-VI
Cirebon Regency	7,16-11,58	II-III
Garut Regency	40,45-131,23	V-VI
Indramayu Regency	7,21-18,40	II-IV
Karawang Regency	7,39-25,77	II-IV
Kuningan Regency	10,3-19,79	II-IV
Majalengka Regency	14,73-24,87	IV
Pangandaran Regency	15,56-31,84	IV
Purwakarta Regency	19,76-32,26	IV
Subang Regency	34,67-47,27	V
Sukabumi Regency	26,55-49,22	IV-V
Sumedang Regency	17,40-43,33	IV-V
Tasikmalaya Regency	7,19-33,33	II-IV
Bandung City	46,27	V
Banjar City	17,47-21,60	IV
Bekasi City	12,13-14,86	II-III
Bogor City	21,037	IV
Cimahi City	49,54	V
Cirebon City	2,16-11,42	III
Depok City	12,99-13,97	II-III
Sukabumi City	54,93	V
Tasikmalaya City	41,69	V

Based on Table 2, it shows that the highest values of ground acceleration and maximum earthquake intensity according to the Lin & Lee method are in Cianjur Regency. The maximum recorded ground acceleration ranged from 30,258 to 135,3164 gal, with earthquake intensity between IV and VI on the MMI scale. In contrast, Cirebon City has the lowest ground acceleration and earthquake intensity values, with maximum ground acceleration ranging from 2,169 to 11,423 gal and intensity III on the MMI scale.

Based on the collected data, a map was created depicting the maximum ground acceleration and earthquake intensity for West Java using the Lin and Lee method, as shown in Figure 4.

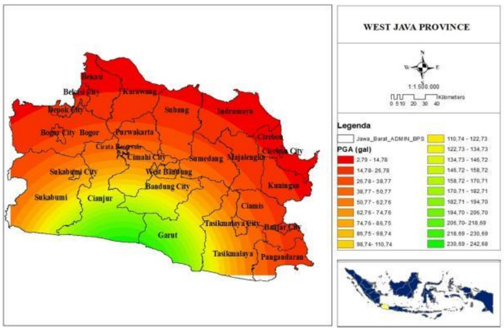

Figure 4. (a) Peak Ground Acceleration Map Using the Lin & Lee Method

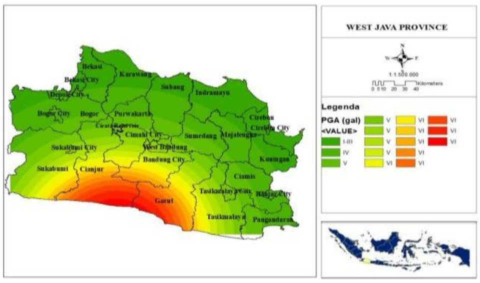

Figure 4. (b) Intensity Scale Map Using the Lin & Lee Method

Based on Figures 4(a) and 4(b), it can be seen that Cianjur Regency has the highest maximum ground acceleration value, because it is located close to the epicenter of the earthquake. Apart from that, Cianjur Regency is also located in the Cimandiri Fault zone which is an active fault in West Java. In contrast, Cirebon City recorded the lowest value because it is located far from the epicenter and is in a relatively fault-free geological area in West Java.

Based on the research results, the maximum ground acceleration values obtained using the Lin & Lee method ranged from 2,16 gal - 135,31 gal. Meanwhile, the McGuire method produces maximum ground acceleration values between 28,90 gal- 195,20 gal. These two methods show that the largest ground acceleration value is found in Cianjur Regency, with a value range of 30,25 gal-135,31 gal and an intensity scale of IV-VI MMI according to the Lin & Lee method. Meanwhile, according to the McGuire method, the maximum ground acceleration in Cianjur reaches 59,24 gal -195,20 gal with an intensity scale of IV-V MMI. This is due to the proximity of the Cianjur area to the earthquake epicenter and its geological characteristics, which have a VS30 value > 360 m/s and consist of alluvium rock and coastal deposits in the form of clay, silt, and sand. This region can be classified as class C according to the Douglas classification. Meanwhile, the lowest maximum ground acceleration value was found in Cirebon City, with a value of 10,17 gal-20.89 gal according to the McGuire method and 2,16 gal - 11,42 gal according to the Lin & Lee method, with an intensity scale of II-IV MMI for both methods. The value of ground acceleration is significantly affected by both the distance from the epicenter and the local geological conditions.

The findings of this research align with those of previous studies. Prior research indicated that the highest peak ground acceleration value in West Java, based on earthquake data from 1974-2016, was found in Cianjur City using both the Matuschka and Donovan methods (Suwandi et al,2017). This maximum ground acceleration value is crucial for earthquake disaster mitigation, particularly for West Java, as it informs the design of earthquake-resistant infrastructure. The results suggest that Cianjur City experiences relatively high peak ground acceleration. Consequently, buildings in Cianjur City should adhere to earthquake-resistant construction standards due to the area's significant seismic activity.

Conclusion

Based on research that has been carried out, the maximum ground acceleration value in West Java ranges between 10.14gal-195.35gal and the maximum intensity value is IV-VI MMI using the Mc Guire method. Meanwhile, for the Lin & Lee method, the range is between 6.65gal-49.24 gal, and the maximum intensity value is around II-V MMI. From the two methods used, the highest maximum ground acceleration value was obtained in Cianjur Regency with a value of 59.24gal - 195.20 gal, and the lowest value was in the Cirebon City area with a value of 28.90 gal using the Mc Guire method. Meanwhile, using the Lin & Lee method, the maximum ground acceleration value The highest value was obtained in Cianjur Regency with a value of 30.49gal-49.24 gal, and the lowest maximum ground acceleration value was in the Cirebon City area with a value of 17.41 gal. Based on the PGA value obtained, it is known that Cianjur Regency has the largest value, this is because Cianjur Regency is close to the epicenter of the earthquake and the local geological conditions.

Acknowledgments

The author wishes to express gratitude to the National Earthquake Information Center (NEIC/USGS) for providing and regularly updating the earthquake data catalog, particularly for West Java, which has been utilized in this research. The author also extends thanks to Microsoft Excel and ArcGIS 10.8 for their software, which greatly assisted in the data processing for this study

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