Seismic Vulnerability Index Mapping Based on PGA, GSS, and MMI Values in Pasar Ujung Kepahiang Village

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Abstract - *Pasar Ujung Village is located in Kepahiang District, which has the highest growth rate and population compared to other sub-districts in Kepahiang Regency, with a growth rate of 1.63% and a population of 53,066 thousand people. As one of the efforts to minimize the occurrence of damage due to earthquake disasters in Pasar Ujung Village, Kepahiang, it is necessary to map the seismic vulnerability index using the microtremor method. The research was conducted in Pasar Ujung Village, Kepahiang. Measurement points were placed at 28 points with a distance of approximately 200 m between points. Primary data used in this study came from microtremor surveys with A0 and f0 values. The results of the study are also included in the high-risk category for the social impact of earthquake disasters with an MMI value of more than 7. Based on the PGA map, it shows that the research location is quite prone to damage due to earthquakes, with a PGA value of > 564gal. Based on the PGA value obtained, the value is classified as instrumental intensity scale VI-VIII with shaking strength in the strong to very strong category. The magnitude of the earthquake, the depth of the source, and the distance of the earthquake source from the research location also contribute. The thickness of the surface sediment layer can be a consideration for people who will carry out development.*

Keywords: *Microtremors; IKS; PGA; GSS; MMI.*

INTRODUCTION

Pasar Ujung Village is located in Kepahiang District. This district has the highest growth rate (1.63%) and population (53,066 people) compared to other sub-districts in Kepahiang Regency (BPS Kepahiang, 2024).

According to the regional geological map of Kepahiang Regency, there are two fault lines that are thought to pass through Kepahiang Regency, namely the Babakan Bogor Fault in the northeast of Pasar Ujung Village and the Musi Fault in the southwest of Pasar Ujung Village. Aluvium (Qa) and Old Kaba Lava 1 are rock formations in Pasar Ujung Village. This formation is formed from sedimentary deposits consisting of volcanic rocks and other sedimentary rocks that have weathered and undergone sedimentation for millions of years. The Old Kaba 1 Formation has distinct morphological characteristics, such as steep slopes and deep valley-shaped topography (Sihombing & Rustadi, 2020).

Pasar Ujung Village is an earthquake-prone area. Historically, Pasar Ujung experienced an earthquake on May 15, 1997, with a magnitude of M 5.0. The earthquake was located 6 km northeast of Kepahiang, at coordinates 3.6 South latitude (LS) and 102.6 East longitude (BT). The earthquake was felt in Pasar Ujung Village with an intensity of V-VI MMI, damaging at least 65 buildings in Pasar Ujung, Kepahiang. Between Pasar Ujung and Pasar Tengah, Kepahiang Regency, there is a ground crack that is approximately one kilometer long. The Geological Agency claims that the Sempiang fault, a branch of the Musi Fault, was the cause of this earthquake (Ardiansyah et al., 1997).

The Musi fault again showed significant seismic activity with a series of earthquakes on October 15 to 20, 2017.

The strength of the earthquakes ranged from M 2.5 to M 3.5, with a maximum intensity of III-IV MMI (BMKG, 2017) (Figure 1).

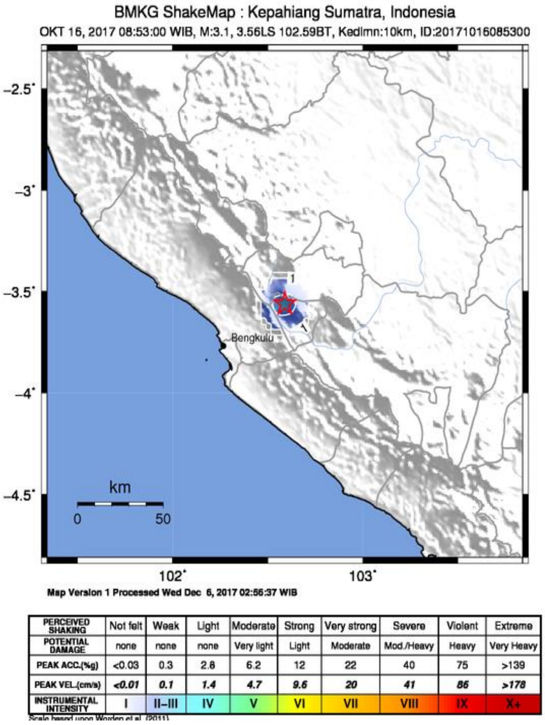

Figure 1. Shake Map BMKG on October 15, 2017.

As we know, earthquakes are characterized by occurring repeatedly in the same area, which means that if an area has experienced an earthquake before, there is a high probability that it will happen again at a certain time. Although there is currently no technology that can accurately predict when and how large an earthquake will occur, areas where earthquakes are likely to occur can already be identified (Al Ansory et al., 2024).

Microtremors are used to analyze soil characteristics, namely dominant frequency (f0) amplification factor (A0), and seismic susceptibility index (Kg). This method is considered cheaper and easier to use, allowing for quick mapping of disaster-prone areas. Surveys are conducted in areas that have not been affected by earthquakes and those that have just experienced an earthquake to see the characteristics of the soil sediment layer, which can be used to determine areas that will experience greater earthquake shaking based on the amplification of ground vibrations, thus helping efforts to reduce the impact of earthquake disasters (Fitri, 2018).

According to (Saaduddin et al., 2015) areas that have lower f0 dominant frequency values and higher A0 amplification factor values will have high Kg seismic vulnerability index values. These areas will be the locations where earthquake damage occurs. To reduce earthquake risk, people can avoid high-risk areas, build infrastructure that meets seismic standards, provide education on mitigation and preparedness, and provide early warning tools. Long-term planning requires a more in-depth disaster risk analysis of space and territory(Hadi et al., 2021).

One of the efforts to minimize earthquake damage in Pasar Ujung Village, Kepahiang, is to map the seismic vulnerability index using the microtremor method. This method is considered cheaper and easier to use, allowing the mapping of disaster-prone areas quickly by conducting surveys in areas that have not yet been affected by an earthquake and those that have recently experienced an earthquake.

RESEARCH METHODS

Measurement of microtremor signals took place directly at 28 points at the research location with a space of 200 m between them. Before the measurements, a survey design was developed to determine the research points based on the location of the epicenter of the earthquake that took place in 2017. The next step was to collect data, which was done by measuring microtremor signals at 28 points of the research location. Data processing was carried out at the Geophysics Laboratory, Department of Physics, Faculty of Mathematics and Natural Sciences, Bengkulu University. The location of this research can be seen in Figure 2.

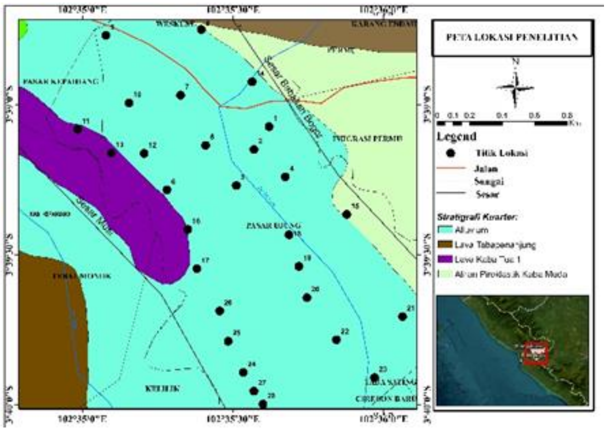

Figure 2. Research Area and Data Collection Points.

The main source of data for this research is microtremor surveys that have f0 and A0 values. There are a few things to do before you can get this info. Latitude and longitude must be used to choose a measurement station first. After that, a seismometer and a compass should be used to measure in relation to north and south. Next, a compass is used to record and capture microtremor data. When collecting data, it's also important to write down important information like the station's coordinates and any disruptions that can cause noise in the vibration waves that are being recorded.

The data obtained in the field from the recording of vibration waves recorded by the seismograph is processed in several stages, namely:

a. Seismic Vulnerability Index Data Processing.

Geopsy software was used to process the data, which was captured by a seismograph and shown as ground vibration wave data on a computer screen. Seismic susceptibility was determined using the dominant frequency (f0) and amplification factor (A0) values from the processed data, both of which were produced from the outcomes of the H/V curve analysis.

According to (Nakamura, 2000) the seismic susceptibility index (kg) can be obtained by squaring the peak value of the microtremor spectrum and then dividing by the dominant frequency. Mathematically it can be written in the following formula.

$$Kg = \frac{A0^2}{f0} \quad (1)$$

b. Ground Shear Strain Data Processing

GSS data processing is done by analyzing the H/V curve consisting of the dominant frequency (f0) and amplification factor (A0) values from the previous data processing results. This was done using Geopsy software, which was recorded by the seismograph through the software.

The calculation of GSS with PGA and Kg parameters is obtained from the multiplication of seismic vulnerability index and maximum ground vibration acceleration. The results of the combination of parameters A0 and f0 from microtremor measurements can be seen in the equation (Nakamura, 2008).

$$\gamma = \left(\frac{A0^2}{f0}\right)\left(\frac{1}{\pi^2 Vb}\right) amax \quad (2)$$

Where Vbb is the speed of large waves on the bedrock and $amax$ is the PGA on the bedrock. The value of Vbb is 750 m/s in accordance with the Indonesian National Standard (SNI).

c. Maximum Ground Vibration Acceleration Data Processing

The highest ground vibration acceleration that has ever occurred at a particular location as a result of an earthquake within a certain period of time is referred to as the maximum ground vibration acceleration. Often used as a parameter to determine the level of risk of an area to earthquakes, the PGA value is calculated by taking into account the earthquake magnitude, the distance of the earthquake source to the calculation point, and the dominant period of the ground (Putri et al., 2017).

Equation 3 shows the calculation of the Peak Ground Acceleration (PGA) value.

$$\alpha g = \frac{5}{\sqrt{T0}} 10^{\,0,61M - (1,66 + 3,6\,R)\,\log R + 0,167 - 1,83\,R} \quad (3)$$

d. Modified Mercalli Intensity Data Processing.

Each earthquake intensity level in the MMI scale is based on the observed effects of the earthquake. Observations are made of ground shaking and the structural damage caused by it. Levels I-IV describe what people see and feel during mild and moderate earthquakes, and levels VII-XII describe how badly structures are damaged during strong earthquakes (Lunga, 2016). The MMI (Imm) value is obtained from the relationship between PGA and MMI at each measurement location point. Equation 4 shows the relationship between PGA and the MMI scale (Imm).

$$Imm = 3{,}66 \log(PGA) - 1{,}66 \quad (4)$$

RESULTS AND DISCUSSION

Results

a. Index of Seismic Vulnerability (IKS)

Seismic susceptibility index (Kg) values are useful for identifying weak areas or areas that may experience damage, as well as soil fractures during wave propagation. This is because the seismic susceptibility index indicates the vulnerability of the deformed soil layers. Higher values indicate that the stability of the soil in the area is lower, and lower values indicate that the damage caused by an earthquake is greater (Nakamura, 2000).

The IKS values at the study site ranged between 0.22 and 10.79. In a study (Nakamura, 2000), it was shown that areas that are frequently damaged have seismic susceptibility index (Kg) values of more than 10 x 10^{-6} to 2 per cm, while areas with minimal damage have seismic susceptibility index (Kg) values of less than 10 x 10^{-6} to 2 per cm.

b. Peak Ground Accelerations (PGA)

PGA is often used to measure how vulnerable an area is to earthquakes. The PGA value is influenced by the earthquake magnitude (M), hypocenter distance (R), and earthquake coordinates. The greater the PGA value that has occurred in a place, the greater the danger and risk of earthquakes that may occur (Edwiza, 2008) Earthquake data for Bengkulu Province from 1994 to 2023 was used, which was obtained from the USGS website. Earthquakes in the period 1994 to 2023 affected the ground acceleration in the provincial area of Kelurahan Pasar Ujung Kepahiang. Calculation of Peak Ground Acceleration (PGA) values using equation 3.

c. Ground Shear Strain (GSS)

The GSS value of a soil layer indicates the ability of the soil layer material to shift due to an earthquake. A higher GSS value in a soil layer indicates the risk of the soil deforming. The seismic susceptibility index (Kg) and the maximum ground vibration acceleration (PGA) at bedrock are mathematically linked to produce the GSS (Sugianto et al., 2017). The GSS value at the study site ranges from 9,2 x 10^{-4} to 6,7 x 10^{-3}.

d. Modified Mercalli Intensity (MMI)

The MMI scale is a qualitative measure of an earthquake, or the scale of an earthquake based on the damage it causes. Earthquake magnitude, distance from the source, local geological conditions, source depth and duration all affect earthquake intensity. The MMI (Imm) value is obtained from the relationship between PGA and MMI at each measurement location.

Discussion

a. Index of Seismic Vulnerability (IKS)

The distribution map of the Index of Seismic Vulnerability (IKS) in the Pasar Ujung Kepahiang urban village area is shown in Figure 3.

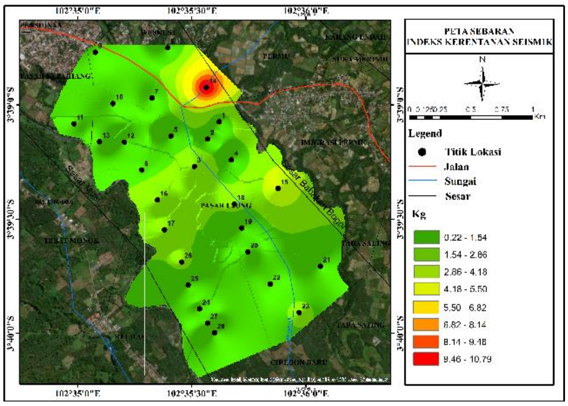

Figure 3. Map of IKS value distribution.

Based on the seismic vulnerability index distribution map above, there are 3 zones with low, medium and high values. The seismic vulnerability index distribution map that shows the highest value is at point T14 with a value of 10.79 which is shown in bright red. Based on the Kepahiang regional geological map, point T14 is located in the alluvium rock formation area (Qa). Rock formations with the lowest seismic wave velocity and bulk density values, which are caused by less compact rocks, can potentially cause vulnerability to earthquake disasters (Hadi et al., 2021). In addition, T14 is close to the river area, which causes a lot of noise during data collection, and close to the Babakan Bogor fault, which causes the highest seismic vulnerability index value.

Seismic vulnerability index values that tend to be moderate are in the range of seismic vulnerability index values 4.18 to 5.50. Green dots indicate that the vulnerability index is small, while yellow dots indicate that the vulnerability index is moderate. The cause of the small to moderate difference in the vulnerability index is because the Pasar Ujung urban village area has a fairly small dominant frequency value, the soil vulnerability index value in the study area is still reasonable, as shown by the spread of green color almost throughout the study area.

b. Peak Ground Accelerations (PGA)

The distribution map of Peak Ground Acceleration (PGA) values is shown in Figure 4.

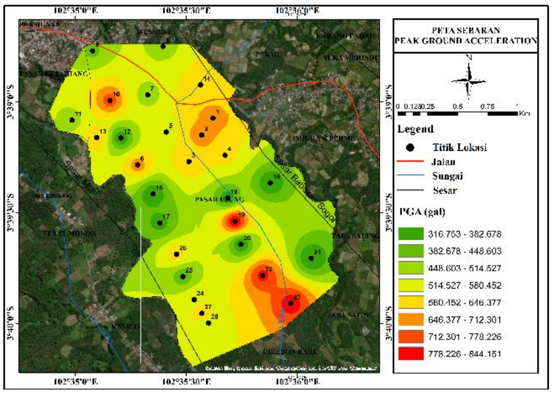

Figure 4. Distribution map of PGA values.

Maximum ground acceleration mapping is depicted by several colors: red, yellow and green. The red color indicates that the earthquake will damage buildings and infrastructure. Figure 2 shows that the maximum ground acceleration is greatest at T10, T19, T22 and T23 with PGA values > 564gal. Based on the PGA values obtained, these values are classified as instrumental intensity scale VI-VIII with shaking strength in the strong to very strong category, while the yellow color indicates that minor damage will occur. Green color indicates that the earthquake will be felt but will not damage buildings. The large PGA value is also due to the fact that Pasar Ujung Kepahiang village is an area traversed by the Musi Fault and the Babakan Bogor Fault (Yulita et al., 2023).

c. Ground Shear Strain (GSS)

The distribution map of GSS values can be seen in Figure 5.

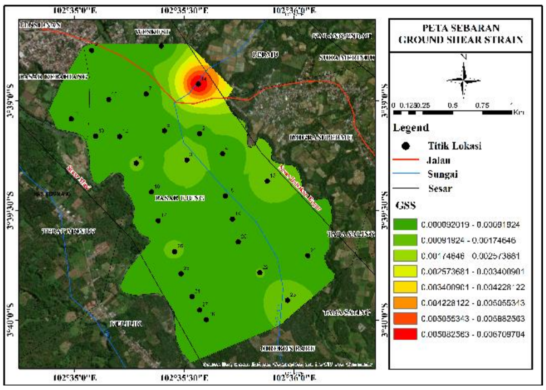

Figure 5. Map of the distribution of GSS values.

The GSS value in Pasar Ujung Village is still in the low category, so it does not cause liquefaction during an earthquake. The lowest Ground Shear Strain value is 9,2 x 10^{-4} at point 12, and the highest GSS value is 6,7 x 10^{-3} at point 14. The high value of point 14 is due to the large Kg value of 10.79. Since the GSS value is strongly influenced by the magnitude of the Seismic Vulnerability Index value, the distribution of the GSS value appears almost the same as the Seismic Vulnerability Index value, while the PGA value is inversely proportional.

Modified Mercalli Intensity (MMI)

According to (Hadi et al., 2012), the level of earthquake risk with a PGA value of 200-300 gal will be equivalent to the Modified Mercally Intensity (MMI) value on the VIII-IX scale (three major risks), while the PGA value of 300-600 gals is equivalent to the MMI value on the IX-X scale (very large risk).

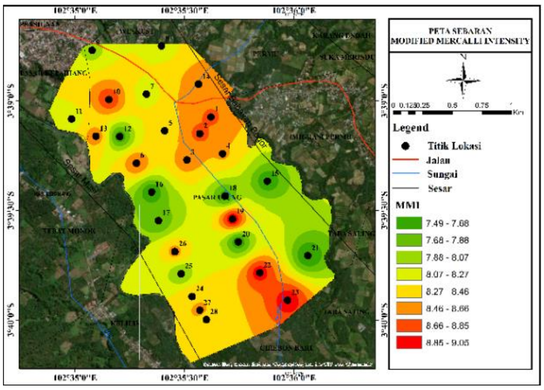

Figure 6. Map of distribution of MMI values.

The MMI distribution map shows the VI scale range at the point with green color. This means that the earthquake was felt by the people and minor damage was caused to buildings with strong construction. Cracks in buildings with poor construction, walls can be separated from the frame of the house, factory chimneys and monuments collapse, water becomes cloudy. Furthermore, the XII scale range is in red. With the highest values in T1, T2, T10, T19, T22, and T23. This means that at that point if an earthquake occurs it will experience heavy damage, causing the building to collapse. Based on the relationship between the PGA and MMI values at each measurement point in Pasar Ujung Kepahiang Village, the MMI value is obtained between 7.49 and 9.05. According to (Wood & Jones, 2014) the value of MMI > 7 is included in the category of high risk of damage caused by earthquake disasters.

CONCLUSION

Based on the research that has been conducted, the level of earthquake hazard in Kelurahan Pasar Ujung Kepahiang is included in the risk level of Large III (200 - 300 gal) and Very Large I (300 - 600 gal).

The GSS value found in the research location ranges between 9,2 x 10^{-4} and 6,7 x 10^{-3}. The research location is also included in the high-risk category for the social impact of earthquakes with an MMI value of more than 7. Based on the PGA map, it shows that the research location is quite prone to damage due to earthquakes, with a PGA value of > 564gal. Based on the PGA value obtained, the value is classified as instrumental intensity scale VI-VIII with shaking strength in the strong to very strong category. The magnitude of the earthquake, the depth of the source, and the distance of the earthquake source from the research location also contribute. The thickness of the surface sediment layer can be a consideration for people who will carry out development.

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