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Mapping of Potential Damages Area in Lombok Island Base on Microtremor Data

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Abstract

Lombok Island and its surrounding is an area that has a high seismicitys level because it is located in the Eastern Sunda Arc. Tectonically, Lombok Island located between the Indo-Australia plate collision zone with Eurasia in the south and the fult of the backarc Bali-Flores in the north. This research's purposed to determine the distribution of vulnerability index and peak ground acceleration value are used to determine the GSS value, so mapping of potential damage areas could be done. The microtremor data taken on 32 observation points distributed in Lombok Island. Microtremor data is analysed using Horizontal to Vertical Spectral Ratio (HVSR) method to get seismic vulnerability index (Kg) and dominant period. Determination of Peak Ground Acceleration (PGA) value using data from the MASE Stasion measurement results based on earthquake events on August 5, 2018. Seismic vulnerability index and peak ground acceleration value are used to determine the GSS value. Determination of potential damage area using analysis of the dominant period, seismic vulnerability indexs and Ground Shear Strain values. The results of this research showed that seismic vulneribility index value in research area is about 0,029 sekon to 1,360 sekon, seismic vulneribility index value is about 0,56 to 189,92 and GSS value is about 2,52 x 10^{-5} to 8,46 x 10^{-3}. The results show that the light damage dominated in East Lombok Districts, the moderate damage is on Mataram City and it dominated in West Lombok Districts. The heavy damage present in the most parts of West Lombok Districts.

Key Words: Microtremor, HVSR, GSS, Vulnerability Index

INTRODUCTION

Lombok Island and its surroundings is an area that has a high level of seismic activity because it is located in the eastern Sunda arc and tectonically the island of Lombok is between the Indo-Australian plate collision zone with Eurasia in the south and a fracture up the Bali-Flores back arc at the north (Ramdani, Setiani & Setiawati, 2019). July 29, 2018 Lombok Island experienced an earthquake with magnitude 6.4, followed by a major earthquake on August 5, 2018 with magnitude 7.0, then followed by aftershocks on August 9, 2018 with magnitude 5.9, August 19, 2018 with magnitude 6.3 (Kompas, 2018). According to BNPB data this series of earthquakes caused 83,392 houses be damaged, 6,231 were severely damaged and the rest were moderately and lightly damaged. Reported as many as 560 people died, 469 people were injured and 396,032 people were displaced.

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Disaster mitigation is an effort that can be done to cope with disaster risks to minimize casualties. The impact of an earthquake can be quantified by using microtremor signal analysis. Microtremor is a weak vibration from the ground caused by natural or artificial disturbances, such as wind, sea waves, traffic and industrial machinery. The HVSR analysis method was developed to calculate the ratio of the Fourier spectrum of the horizontal component microtremor signal to its vertical component Ground Shear Strains (GSS) can show the ability of a layer of soil to stretch and shift when an earthquake occurs (Francisco & Sesma, 2017). GSS can be used to characterize the impacts that occur when an earthquake, such as liquefaction, soil cracking, land subsidence, landslides and vibrating soil. The level of damage that occurs due to the earthquake is influenced by the quality and strength of the building, geological and geotectonic conditions as well as the maximum ground acceleration in the area where the earthquake occurred (Timur, Ozicer, Sari & Uyanik, 2015).

Mapping areas of potential damage been conducted in the municipality of Denpasar and surrounding (Murdiantoro, Sismanto & Marjiyono, 2016). Based on the seismic vulnerability index map, the value of the seismic vulnerability index ranges from 0.103-33.78. High Kg values are in the District of South Denpasar, namely 0.29-33.78. Based on the distribution map of ground shear-strain, the value of ground shear-strain ranges between with the average value between being in the entire study area. Based on the vs30 distribution map, the value of vs30 ranges between 171.32 - 764.62 m/s. South Denpasar District has a low vs30 value. Potential damage to infrastructure is closely related to the characteristics of soil movement and soil classification. Based on the results of the analysis, South Denpasar District has the highest damage potential compared to other districts. Based on the analysis of vs30, the type of soil in South Denpasar District is soft soil.

The study in North Lombok Regency, shows that the dominant period value in the study area has a minimum value of 0.07 seconds and a maximum value of 1.59 seconds. The dominant frequency value of the study area also ranged from 0.627 Hz to 14.04 Hz. The results of the vulnerability index in the study area show values varying between 0.3×10^{-6} to 173×10^{-6}. The spatial distribution of GSS values in the 2 villages varied $(0.37–42.37)\times10^{-4}$ (Fatimatuzzahrah, Didik & Bahtiar, 2020).

BMKG (2018) with survey and field mapping in Lombok resulted in T_0 values obtained in the study area ranging from 0.16 to 4.5 seconds. This research also found that the vulnerability index values range from moderate to high. The distribution patterns shown in the two maps are relatively similar. Classification of the level of damage represented by each type of color. In the red zone describes the worst damaged condition (heavily damaged), the yellow zone describes the level of moderate vulnerability or has the potential level of medium damage, the green zone describes the area that has the smallest potential damage.

The purpose of this study is to determine the distribution of the dominant period (T_0) value, the distribution of the seismic vulnerability index (K_g) value, the distribution of the Ground Shear Strain (GSS) value, and the distribution of the damage zone on Lombok Island.

Geological Setting

The location of this research is located on the island of Lombok, West Nusa Tenggara Province which has a geographical location at 115°45'EL - 116°45'EL and 8°00 'SL - 9°00' SL. Lombok Island has the northern part bordering the Flores Sea, the southern part bordering the Indian Ocean, the western part bordering Bali and the eastern part bordering Sumbawa Island. This study has 32 measurement points scattered throughout the island of Lombok, it aims to be able to evenly distribute the entire region on the island of Lombok.

Figure 1 shows the geological conditions on Lombok Island, Lombok Island that has relatively young rocks (Agustawijaya, Sulistiyono & Elhuda, 2018). The island of Lombok was formed due to the volcanoes produced by the subduction of the Indo-Australian plate with Eurasia. Rocks on Lombok Island are dominated by volcanic rocks, such as breccia; namely rocks with a rough texture in the form of fragments of more than 2 mm and angled, tuff; falling rocks or pyroclastic flows with fragments of less than 2 mm, and lava. Rock, which is a freezing flow of magma that has come out to the surface of the earth. Rocks on Lombok Island also have carbonate rocks, which are coral reefs that have risen to the surface.

Southern Lombok is composed of volcanic breccia rocks (the material is volcanic rocks) and lava with the age of Early Miocene rocks (20 million years ago) to the Pliocene-Pleistocene (3.6-1.8 million years ago). The Scavenger Formation and the Kawangan Formation are in the southern part of Lombok Island, which is tectonically at the front (forearc). Basaltic igneous rocks intrude volcanic breccia and sandstone rocks of the Scavenger Formation and Kawangan Formation in some places. The northern part of Lombok Island, which is around Rinjani Volcano, rocks consist of inseparable volcanic rock consisting of lava, breccia, loose tuff and aged Quarter (2.6 million years ago - today). The oldest rocks on the island of Lombok are rocks from the Pengulung and Kawangan Formations, aged Oligocene formed from underwater volcanic activity due to tectonic symptoms (Lavigne, et al., 2013).

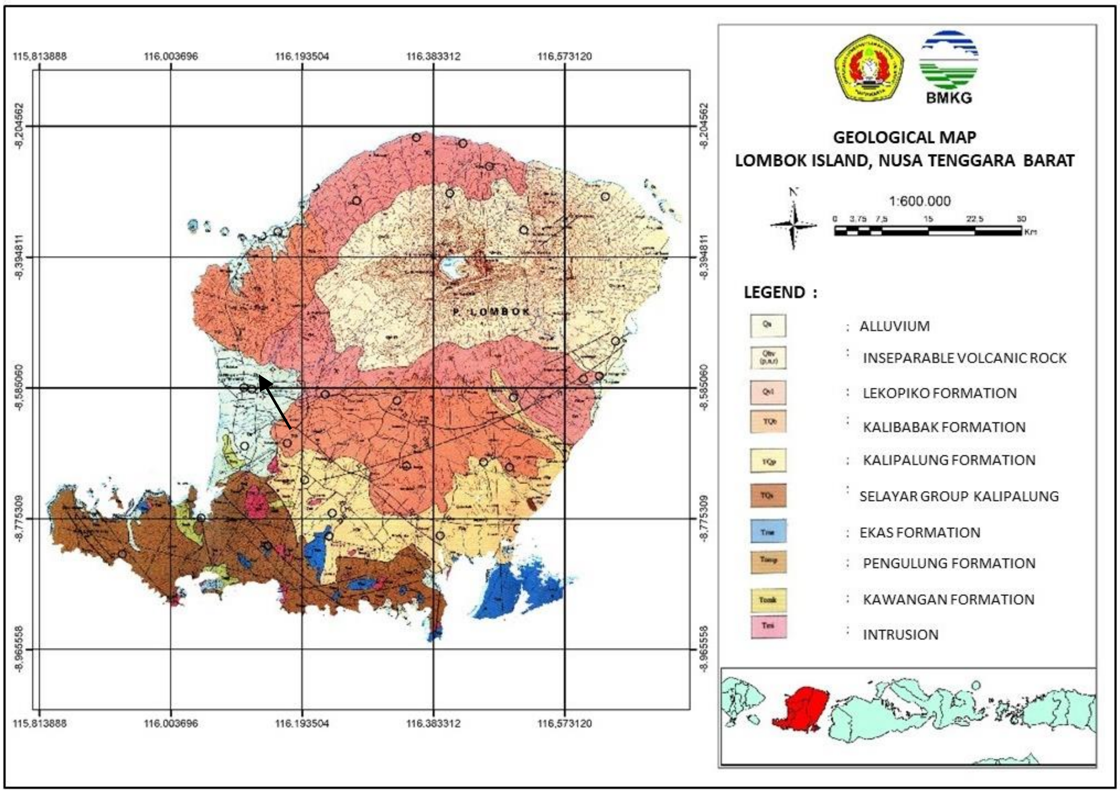

Figure 1. Regional Geological Map of the Research Area.

METHODS

Microtremor

Microtremor is a natural vibration caused by two main types of sources, namely sources originating from human activities and sources originating from natural activities (Nakamura, 2008). Microtremor is a vibration that continues to occur constantly sourced by all activities that occur on the surface of the earth.

Microtremor is a ground vibration that has a shift amplitude of 0.1-1 µm and vibration velocity between 0.001 to 0.1 cm/s. Microtremor can be classified into two types if viewed from the period. The first type is a short period in which this type has a period value of less than 1 second and the second type is a long period where the period value is more than 1 second, the source of vibration used can be sourced from storms and sea waves (Rezaei & Choobbasti, 2017).

Horizontal to Vertical Spectral Ratio (HVSR)

HVSR is a method that has a basis on the assumption that the ratio between the horizontal spectrum and the vertical spectrum of surface vibrations is a function of displacement. This shows that the dynamic characteristics of the existing layers on the surface can be roughly understood if at the observation point the observations of the microtremor seismic waveform are made using a press having three recording components, where two components have a horizontal axis and one component with a vertical axis (Nakamura, 2008).

The magnitude of the amplification factor of horizontal and vertical movements on the surface that uses seismic movements that come into direct contact between the bedrock and the ground surface as a reference. TH and TV represent the horizontal and vertical amplification factors; we get new equation:

$$T_{SITE}\frac{T_H}{T_V} = \frac{S_{VS}}{S_{VB}} \quad (1)$$

The equation can be translated so that it becomes:

$$HVSR = T_{SITE}\frac{\sqrt{(S_{North-South})^2+(S_{East-West})^2}}{S_{VS}} \quad (2)$$

Amplification (A_0)

Amplification is a magnification of seismic waves that occur due to differences in violence between two different media. The greater the difference in layer hardness between the two mediums that are passed by seismic waves, the magnification of the seismic waves will also be even greater. The value of the amplification factor is related to the comparison of the contrast value of the impedance of the surface layer with the layer below it. If the value of the comparison between the two is greater than the value of reinforcement or amplification is also greater, it also applies to the opposite (Nakamura, 2008). There are two causes amplification of seismic waves that can cause damage to buildings. The first is the wave that is trapped in the soft layer so that the wave will experience a superposition that can cause these waves to strengthen each other. Secondly, there are similarities in the natural frequency of the area with the building so that the ground vibrations that occur in the building are even greater.

Dominant Frequency (*f_0*)

Dominant frequency is the frequency value that often appears in a measurement area so that the value is considered to represent the natural frequency value of the rock layer of the area; the dominant frequency value is considered able to show the characteristics of the rock layer of the area (Ipmawan, Permanasari & Siregar, 2018). The value of the dominant frequency is influenced by the thickness of the soil layer that is on the surface, so the smaller the dominant frequency value of the area, it shows that the thicker the soil layer from the base rock. The frequency of observation limits for microtremors in general are between 0.5-20 Hz and small frequencies can reach 0.2 Hz

Dominant Period (T_0)

The dominant period value is the time required for the microtremor waves to spread through the sedimentary layer on the surface, the dominant period value is generally used to determine the characteristics of the hardness of the soil layer in an area (Fallahi, Samaei. & Karashi, 2019). The value of the dominant period is closely related to the thickness and level of hardness of the surface layer. In other words, regions that have a high dominant period value generally have the vulnerability to experience greater damage if an earthquake occurs. That is because the value of the dominant period is directly proportional to the value of the amplification. The value of the dominant period can be determined by equation (Arifin, Marjiyono & Mulyanto, 2014).

$$T_0 = \frac{1}{f_0} \quad (3)$$

Where :

T_0 : dominant period (seconds)

F_0 : dominant frequency (Hz)

Vulnerability Index (K_g)

Vulnerability index is an index that can show the level of vulnerability of the surface layer of an area to soil deformation when an earthquake occurs. If an area has a high seismic vulnerability index value, the potential of the area to deform when an earthquake is very large, while a region that has a small vulnerability index value, the potential for deformation in that area is also low.

Damage to buildings caused by the presence of an earthquake can occur when the force of an earthquake exceeds the limit of a building's strain. This can result in displacement of the basic position (foundation) of a building or can occur collapse in buildings that have low structural stability (Nakamura, 2008).

The seismic vulnerability index (K_g) can identify the level of vulnerability of an area, that is experiencing deforestation due to the earthquake with the equation (4).

$$K_g = \frac{{A_0}^2}{f_0} \quad (4)$$

Where :

K_g : Seismic vulnerability index

A_0 : Amplification

f_0 : Dominant frequency (Hz)

Peak Ground Acceleration (PGA)

According to Hadi, Brotopuspito, Pramumijoyo, & Hardiyatmo (2018), the maximum ground vibration acceleration or Peak Ground Acceleration (PGA) is the largest ground value of vibration acceleration ever occurring in an area where it is caused by an earthquake. The PGA value of an area is calculated through the impact of an earthquake in the specified time bracket, where the amplitude and distance between points with the hypocenter can affect the amount of the PGA value. Acceleration of ground vibrations is a disturbance that needs to be examined every time a ground vibration occurs and a maximum vibration acceleration value is chosen so that it can provide an understanding of the most severe effects ever experienced in an area (Gustiana, Pujiastuti and Minangsih, 2018).

Measurement of the value of land acceleration can be done with an accelerograph installed in the study area. Determining the value of land acceleration can also be done in other ways if the installation of tools in the study area cannot be done (Laouami, 2020). Another method is to use empirical methods, namely by using the approach of several equations derived from several earthquake parameters.

Ground Shear Strain (γ)

Ground Shear Strain (GSS) is the ability of a layer of soil material to stretch and shift during an earthquake. Areas that have high GSS values have a high risk of soil movement due to earthquakes, such as land subsidence, ground vibration, and soil stretching. To calculate the GSS of a surface layer in an earthquake. The value of the Ground Shear Strain (γ) can be calculated using the equation (5).

$$\gamma = \mathrm{K}_g \mathrm{x}\ (10^{-6})\ \mathrm{x}\ \alpha_\mathrm{g} \quad (5)$$

γ is the ground shear-strain, K_g is the seismic vulnerability index, 10^{-6} is set to estimate the strain value at the unit 10^{-6} on the surface soil layer, and α is the maximum soil acceleration (PGA) in the bedrock.

RESULT AND DISCUSSION

Distribution of Dominant Period Values (T_0)

The results of data processing on the dominant period parameters have a minimum value of 0.030 seconds and a maximum value of 1.36 seconds. The smallest dominant period value is located at the measurement point in the village of Akar - akar in the North Lombok Regency. Whereas the largest dominant period value is located at, the measurement point located at the measurement point located in Central Sekotong Village, West Lombok Regency. Figure 2 shows the distribution of the dominant period values on Lombok Island.

The dominant period interpreted as the time required by microtremor waves to propagate through the surface sediment deposition layer or experience one reflection of the reflecting plane to the surface. The dominant period value interpreted to determine the soil characteristics at the measurement point (Ipmawan, Permanasari & Siregar, 2019).

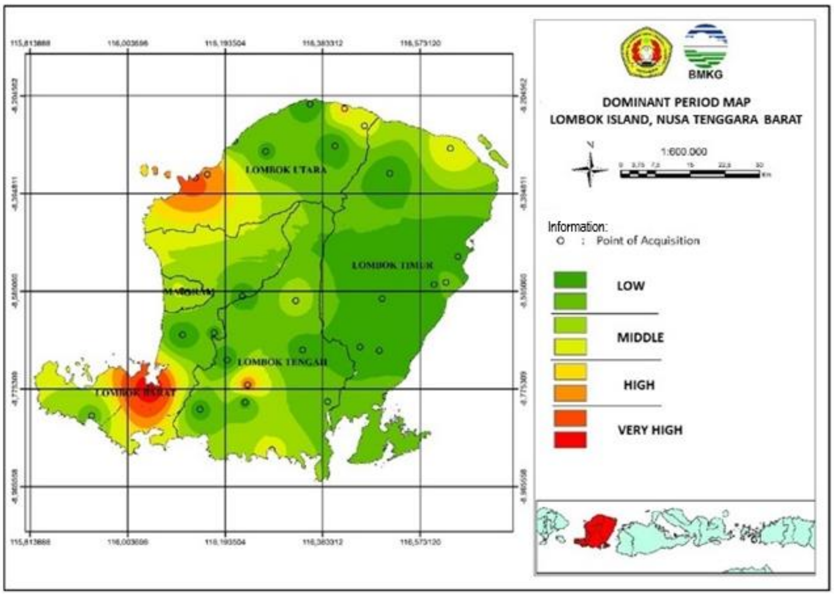

Figure 2. Distribution of Dominant Period Values

Table 1 used for reference to the interpretation of T_0 parameters in the Lombok Island. The table in its manufacture uses references from Zhao (2006) classification, and the Kanai – Omote – Nakajima (BMKG, 1998). Determination of the range in the table adjusted to the T_0 value in the study area.

Table 1. Classification of Dominant Period Values on Lombok Island

Grade Level	Natural Period (Sec)	Rock Characteristics	Description
Low	0.029 - 0.25	Hard	Rock
Intermediate	0.25 - 0.50	moderat	Hard Soil
High	0.50 - 0.75	Soft	Medium Soil
Very High	0.75 - 1.36	Very Soft	Soft Soil

Reviewing the table, the North Lombok area dominated by low T_0 values and can classified as soil conditions in the form of rocks that have relatively thin surface deposits with hardness characteristics. The result of this calculation is in accordance with the results of Fallahi, Samaei & Karashi (2019) research. This is thought to cause by the geological conditions in the area in the form of massive rocks so the T_0 value is relatively small. The western part of North Lombok Regency has an area with a relatively high T_0 value classified as soil conditions in the form of medium soil with a soft hardness level, in that area it is estimated to have a thick enough alluvial deposit which results in a high T_0 value.

East Lombok Regency dominated by low T_0 value, where the area classified as rock that has a hard level of violence. Central Lombok dominated by low dominant period values classified as hard rock and hard soil with moderate hardness characteristics. West Lombok Regency dominated by T_0 value of 0.25 to 0.5 classified with hard soil and has moderate characteristics.

Distribution of Vulnerability Index Values (K_g)

From the results of data processing in Figure 3 the parameter of vulnerability index (K_g) has a minimum value of 0.57 and a maximum value of 189.62, over all the vulnerability index value obtained varies greatly from each point. The smallest vulnerability index value is located at the measurement point in the village of South Sakra in East Lombok Regency. Whereas the highest vulnerability index value is located at the measurement, point located at the Central Sekotong Village, West Lombok Regency.

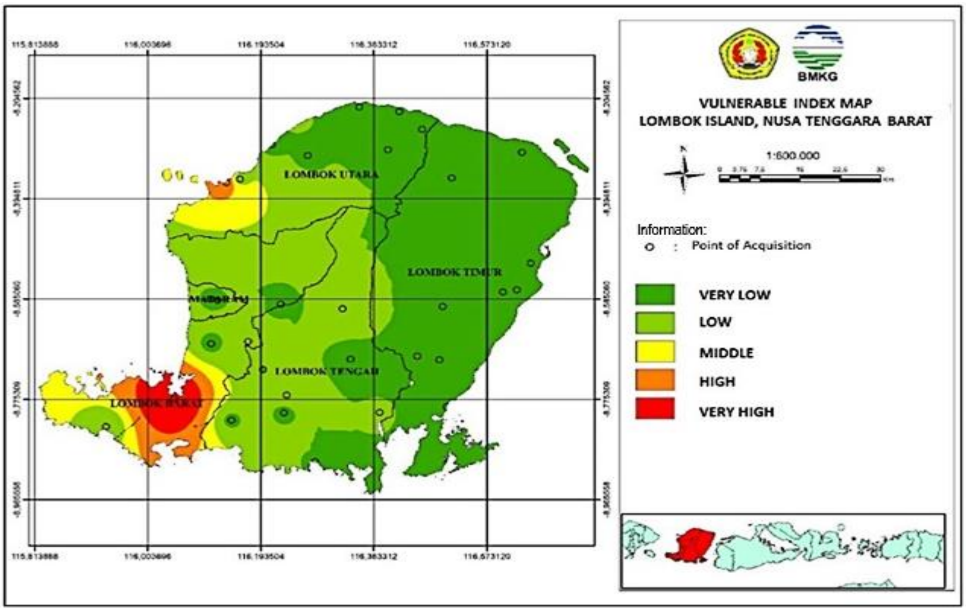

Figure 3. Distribution of Vulnerability Index Values

Table 2 is a table used for reference interpretation of K_g parameters on the island of Lombok. The table in its construction uses references from the Daryono (2013) classification table. The determination of the range of values in the table is adjusted to the K_g value in the study area.

Table 2. Classification of Vulnerability Index Values on Lombok Island

Classification	Vulnerability Index Value	Vulnerability rate
Very Low	0.568 – 5	Very Light
Low	5.001 – 20	Light
Intermediate	20.001 – 40	Intermediate
High	40.001 – 80	Danger
Very High	80.001 - 189.716	Very Danger

North Lombok Regency dominated by K_g values of 0.568 to 5, where these classified as very low levels of vulnerability. The western part of North Lombok Regency is an area that has a value of 20 to 40 and has a moderate level of vulnerability. East Lombok Regency dominated by a low K_g value of 0.568 to 5, the area classified as a very low level of vulnerability. Central Lombok Regency dominated by K_g values of 5 to 20 that area classified as low vulnerability. West Lombok Regency has areas classified as low vulnerability, where the area has a range of values from 5 to 20. West Lombok also has areas classified as very high vulnerability with Kg values of 80 to 189,716. Mataram city area has a vulnerability index value of 5 to 20 that classified at a low vulnerability level.

Distribution of Ground Shear Strain (GSS)

The results of data processing in Figure 4, the GSS parameters at the study site have a minimum value of 2.5293 x 10-5 and a maximum value of 8.4603 x 10-3. The smallest GSS value is located at the measurement point in the South Sakra Village in East Lombok Regency and the largest GSS value is located at the measurement point located at the Central Sekotong Village in West Lombok Regency. On the results of the GSS value, an area with a high GSS value will cause the soil in the area to stretch and swell when an earthquake occurs. Areas that have high GSS values have a high risk of ground movement caused by earthquakes, such as land subsidence, ground vibration and soil stretching.

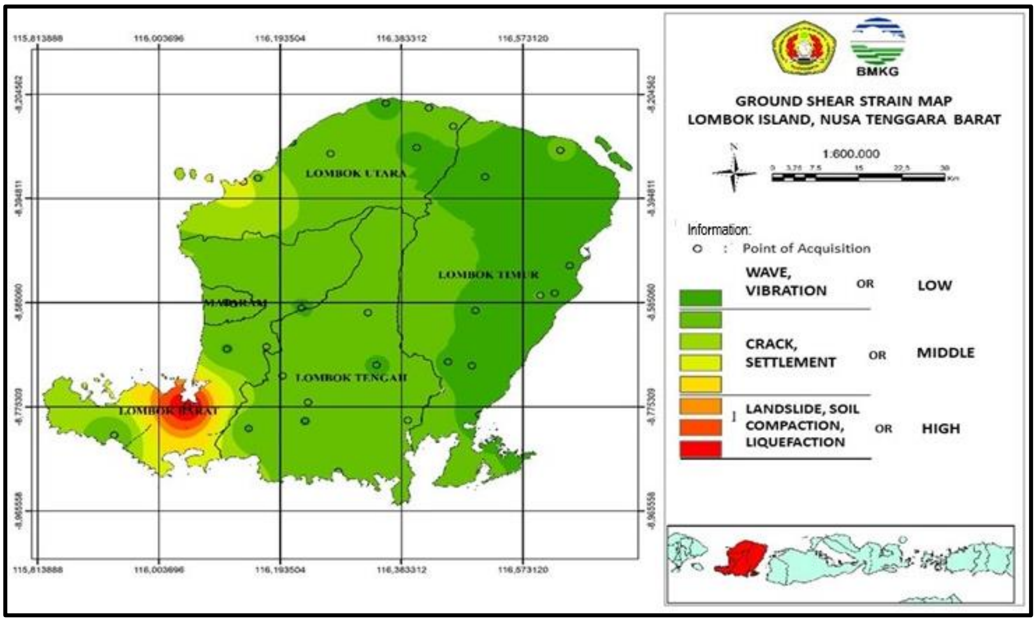

Figure 4. Distribution of Ground Shear Strain Value

Table 3 is a table used for reference interpretation of GSS parameters on the island of Lombok. The table in its making uses reference from the Classification table made by Ishihara, 1996. Determination of the range of values in the table adjusted with the GSS value in the study area.

Table 3. Classification of Ground Shear Strain Value on Lombok Island

Classification	GSS value ($x10^{-4}$)	Phenomena
Low	0.25 – 1.00	Wave, Vibration
Intermediate	1.00 – 40.1	Crack, Settlement
High	40.1 – 84.1	Landslide, Soil Compaction, Liquefaction

North Lombok Regency has a GSS value of $1x10^{-4}$ to $2.49x10^{-3}$, if it reviewed in table 3 then the area is included in an area that has a GSS in medium size and the worst possibility is that the area will experience phenomena in the form of fractures or land subsidence. East Lombok Regency dominated by a small GSS value, which is $2.53x10^{-5}$ to $1x10^{-4}$. East Lombok area if experiencing an earthquake will experience a phenomenon in the form of vibration or just feel the earthquake waves. The area of East Lombok has a small GSS value because the geology of the area is the massive rock produced from Mount Rinjani. Central Lombok dominated by GSS values of $1x10^{-4}$ to $7.48x10^{-4}$.

Central Lombok Regency has a small GSS value because the area is an area with massive rocks resulting from Mount Rinjani will experience phenomena in the form of fractures or land subsidence. West Lombok Regency is an area that has a high GSS value of $5.05x10^{-3}$ to $8.41x10^{-3}$, if the area experiences an earthquake it may experience phenomena such as landslides, compacting, or liquefaction.

Potential Damages Area in Lombok Island

Figure 5 shows the vulnerability of an area in the occurrence of infrastructure damage. Mapping of earthquake damage in Lombok Island based on analysis of ground shear strain, seismic vulnerability index, and dominant period. These three parameters relate to land deformation that will cause damage to buildings and infrastructure that is on the ground or on the surface (Timur, et al., 2015). The dominant period value used to determine the level of hardness of the deposited surface layer of an area. Seismic vulnerability index value used to indicate the level of vulnerability to deformation when an earthquake occurs. The ground shear strain value used to determine the risk of an area to ground movement (Laouami, 2020).

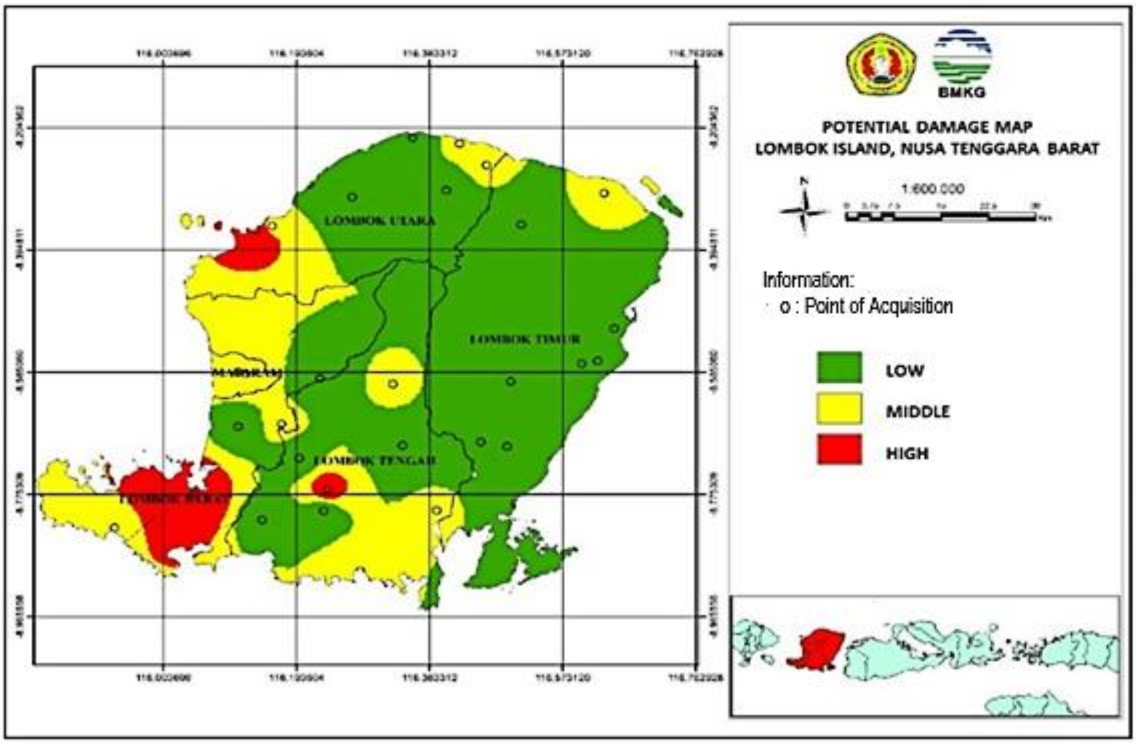

Figure 5. Distribution of Potential Damaged Area in Lombok Island

Table 4 is a table used for reference determining the level of damage on the island of Lombok. The table in its manufacture uses the results of the interpretation of the dominant period, vulnerability index and ground shear strain. The three maps illustrate the distribution of the respective parameter values in the Lombok island area.

Table 4. Results of Regional Conditions in Lombok Island from Parameters T_0, K_g and GSS

K_g	T_0	GSS	Damage Classification
Very Low	Low	Low	Light
Low Intermediate	Intermediate	Intermediate	Intermediate
High Very High	High Very High	High	Heavy

The red zone is a zone with a high level of vulnerability, in that zone it can expected that the building would heavily damage. The red zone has a moderate to soft rock hardness level, has a high level of susceptibility to deformation and the soil is very easy to shift. Yellow zone is a zone with a moderate level of vulnerability, in that zone will have the potential for moderate damage. In the yellow zone, the level of soil type is hard soil, the level of susceptibility to moderate deformation and soil conditions are stable enough to withstand displacement due to earthquake. Green zone is a zone with a low level of vulnerability, so building damage will classified as mild damage. In the green zone, it has a level of soil type in the form of rocks; the level of vulnerability to small deformations and soil conditions can said to be stable to withstand displacement due to earthquakes.

CONCLUSION

Based on the map of the distribution of dominant period values, the value of the dominant period is between 0.029 seconds to 1.360 seconds. The dominant period value in North Lombok Regency is in the moderate to high level, East Lombok Regency is in the low to moderate level, Central Lombok Regency is in the moderate to high level, West Lombok Regency is in the low to very high level, Kota and Kota Mataram in the intermediate level.

Based on the map of the distribution of vulnerability index values, the K_g value ranges from 0.56 to 189.92. North Lombok regency Kg value consists of very low to high levels, East Lombok regency consists of very low to low levels, Central Lombok regency consists of very low to low levels, West Lombok regency consists of very low to very high levels, and Mataram City consists of very low to low levels.

Based on the distribution map of Ground Shear Strain (GSS) values, the GSS values range between 2.52 x 10^{-5} and a maximum value of 8.46 x 10^{-3}. The GSS value of North Lombok Regency consists of low to medium level, East Lombok Regency consists of low to medium level, Central Lombok Regency consists of middle level, West Lombok Regency consists of middle to high level and Mataram City consists of medium level.

Based on the results of the analysis of T0, Kg, and GSS values to determine areas prone to damage, the green zone is spread over most of East Lombok Regency, the middle part of North Lombok Regency, a small part of West Lombok Regency and the northern part of Central Lombok Regency. The yellow zone is spread in the western and northern parts of the North Lombok Regency, the northern part of East Lombok Regency, the southern and central part of Central Lombok Regency, most of the West Lombok Regency and the whole of Mataram City. The red zone is spread in the southern part of West Lombok Regency, the western part of North Lombok Regency, and a small part in Central Lombok Regency.

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