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LOCAL GEOLOGY AND SITE CLASS ASSESSMENT BASED ON MICROTREMOR DATA IN NORTH LOMBOK

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ABSTRACT

Lombok Island is an active seismic area in Indonesia potentially hit by an earthquake due to located between two earthquake generators from the South and the North. Several large earthquakes rocked Lombok, an earthquake with a magnitude of 6.4 on July 29, 2018, and 7.0 on August 5, 2018. This study aims to determine the characteristics of the local site effect based on the dominant frequency value (f_0), soil amplification (A_0), sediment layer thickness (d), v_{s-30}, dominant period (T_0), and seismic vulnerability index (K_g) and to comprehend the soil class (site class) based on the thickness of the sediment layer (d), and v_{s-30} in the North Lombok region. The data used is secondary data from microtremor signal recordings in North Lombok Regency in 2018. Data processing used Geopsy software, and microtremor data were analyzed using the HVSR method. From processing the HVSR data, the dominant frequency value about (0.8 - 18) Hz, amplification value (1.7 – 9.7), dominant period value (0.05 – 1.2) seconds, seismic vulnerability index value $(0.4 – 71) \times 10^{-6} \ s^2/cm$, and the value of v_{s-30} in the study area (20.05 – 287.04) m/s. Based on microtremor analysis, the local site effect indicates that alluvium rocks caused stronger earthquake vibrations and more damage. Whereas the Kalibabak and Lekopiko formations caused fewer earthquake vibrations and less wear. Based on the dominant period and v_{s-30}, area study classify as Site Class IV class E and Site Class III class D

Introduction

The Indonesian archipelago is a junction of three main tectonic plates: the Indo-Australian plate in the South, the Eurasian plate in the North, and the Pacific plate In the East [1]. The existence of this plate interaction places Indonesia as an area that is very prone to earthquakes. An earthquake is an occurrence shaking the earth due to a sudden shift in the rock layers in the earth's crust due to tectonic plates' movement [2]. The movement of these tectonic plates causes volcanic arcs, one of which is Lombok Island. Lombok Island is flanked

by two earthquake sources, from the South and North; there is a subduction zone from the south Indo-Australian plate that goes down the island of

Lombok. At the same time, there is the Flores reverse Fault (Flores Back Arc Thrust). This reverse fault extends from the Bali Sea to the east to Flores. Besides, the island of Lombok also has loose, thick, porous, stocky, and fault-based soil conditions. Lombok has considerable potential for earthquakes [3].

From July to September 2018, a large earthquake rocked Lombok. The earthquake caused many casualties and severe damage to the North Lombok Regency and East Lombok Regency [4]. So, an initial study is needed as an effort in disaster management. One of these efforts is to study subsurface conditions using microtremor analysis [5]. Microtremor is a wave that propagates on the surface. These waves are due to humans, such as vehicle traffic, factory machines, and so on, recorded in natural vibrations [6].

Analysis of natural vibrations in a specific area caused by local geological effects depends on the soil's dynamic characteristics or rock. The building stands or referred to as the local site effect [7]. An area with the same geological conditions can respond to ground vibrations' impact depending on the formation's lithology constituents' characteristics. This phenomenon is called the site effect. The cause of the local site effect is the dominant frequency (f_0) and soil amplification (A_0) of the microtremor natural vibration analysis using the HVSR method. The local site effect showed by the thickness of the sediment layer (d), the seismic vulnerability index (Kg), the dominant period (T_0), and average velocity to a depth 30 meters (v_{s-30}).

Several researchers have researched the HVSR method in Indonesia [8, 9, 10]. From some of these studies, no one has investigated the Lombok area, especially in North Lombok, as it has suffered severe damage due to the 2018 earthquake.

Microtremor is a minimal and continuous ground vibration that originates from various kinds of pulses such as traffic, wind, human activities, and so on [11]. Microtremor, also known as ambient vibration, comes from two primary sources: nature and humans. At low frequencies below 1 Hz, the microtremor source is natural. Ocean waves give rise to ambient vibration with a frequency of about 0.2 Hz. In comparison, about 0.5 Hz is caused by the interaction between the ocean and shore waves. For frequencies below 0.1 Hz, the microtremor is associated with activity in the atmosphere. At high frequencies of more than 1 Hz, human activities such as traffic vehicles, machines, and others are the primary source. Source location is usually at ground level and varies day and night [12].

Microtremor is a ground vibration with a displacement amplitude of about (0.1 - 1) μm and a velocity of (0.001 to 0.01) cm/s. Microtremors are classified into two types based on their period range. The first type is a short period microtremor with less than 1 second. It is associated with shallow subsurface structures, several tens of meters thick. The second type is a long-period microtremor with a period of more than 1 second. This condition is related to deeper soil structure, showing the basis of hard rock [13]. The variables obtained from the HVSR method are:

- **Dominant frequency** (f_0) is the frequency value that often appears. It is recognized as the rock layers' frequency value to show the rock's type and characteristics. According to [11], soil types classification is based on the predominant microtremor frequency show in Table 1.

Table 1. Classification Based on Microtremor Dominant Frequency Value by Kanai [11]

Soil Classification		Dominant Frequency (Hz)	Kanai Classification	Description
Typ e	**Kind**			
IV	I	$6,7 \leq 20$	Tertiary or older rock. They consist of Hard Sandy, gravel, etc.	Sediment thickness the surface is skinny, dominated by rock.
III	II	$4 \leq 6,7$	Alluvial rock with a thickness of 5 m. consists of sandy-gravel, hard sandy clay, loam, etc.	Surface thickness falls into the thick category of about (5 – 10) m.
II	III	$2,5 \leq 4$	Alluvial rock with thickness> 5 m. consists of sandy-gravel, hard sandy clay, loam, etc.	Surface thickness falls into the thick category around (10 - 30) m.
I	IV	<2,5	Alluvial rock, as a result of sedimentation from the delta, topsoil, mud, etc. The thickness of sediment more than 30 m	Sediment thickness the surface is very thick

- **The dominant period's (T_0) value** is when it takes microtremor waves to propagate through the surface sediment deposition layer or experience one reflection of the plane of reflection to the surface. This dominant period is an inversion of the dominant frequency.
- **Amplification factor (A_0)** is an enlargement of seismic waves that occurs due to significant differences between layers. The soil amplification value is related to the contrast ratio between the surface layer's impedance and the layer below it [14]. If the two layers' impedance contrast ratio is high, the gain factor value is also high, and vice versa. The amplification value is directly proportional to the horizontal and vertical (H/V) spectral ratio [15]. The amplification value can increase if the rock has undergone deformation (weathering, folding, or expansion), which changes the rock's physical properties. The amplification value could vary according to the rock body's deformation in the same rock. Based on these values, it, then, is classified based on high and low values, as shown in Table 2**.**

Table 2. Classification of the amplification factor (modified from [16])

Value of A	Classification
A < 3	Low
$3 \leq A < 6$	Moderate
$6 \leq A < 9$	High
$A \geq 9$	Very high

- **The seismic vulnerability index (Kg)** is an index that describes the level of vulnerability of the surface soil layer to soil deformation during an earthquake [17]. The seismic vulnerability index's value is related to the level of vulnerability of an area, so the risk of earthquakes' risk of damage due to earthquakes is getting more significant [18]. The seismic vulnerability index value obtained has taken into account the local geological conditions (local site effect). In areas with high seismic vulnerability index values, the resonance frequency is very low. This phenomenon indicates that the sedimentary layer covering the bedrock is relatively thick. A thick layer of sediment, if a high amplification value accompanies it, the layer will produce a sizeable seismic vulnerability index value. According to [19], the classification of the seismic vulnerability index is presented in Table 3.

Table 3. Classification of the seismic vulnerability index (Kg) (modified from [19])

Value of Kg	Classification
< 3	Low
$3 \leq Kg \leq 6$	Moderate
> 6	High

- **Sediment thickness (d)** is one of the factors that cause the local site effect during an earthquake. The natural frequency influences the thickness of the sedimentary layer. The natural frequency is inversely proportional to the thickness of the sediment layer. The smaller the natural frequency, the greater the thickness of the sediment layer, and vice versa. The dominant period of seismic waves in an area is directly proportional to the sediment layer's thickness [20]. The thickness of the sediment layer can be estimated using the H/V spectrum ratio. The method is based on the trapping of SH wave vibrations in the sediment medium above the bedrock. The relationship between sediment thickness and dominant frequency can be determined based on the rules for closed the Organa pipes [21]

Method

The data used is micro-seismic data measured by the Centre of Volcanology and Geological Hazard Mitigation (PVMBG) in 2018. The number of points is 22 measurement points, which distributed as shown in Figure 1. The measuring instrument used is a seismometer with the LE-3D/5sMkIII type (Figure 2), and each point is measured/recorded for 60 minutes.

Figure 1. Distribution of microtremor points

Figure 2. Seismometer LE-3D/5s MkIII type

The data processing in this research use Geopsy (2.9.1) and Surfer 13 for plotting the results of data processing. The procedure of the research is shown in Figure 3.
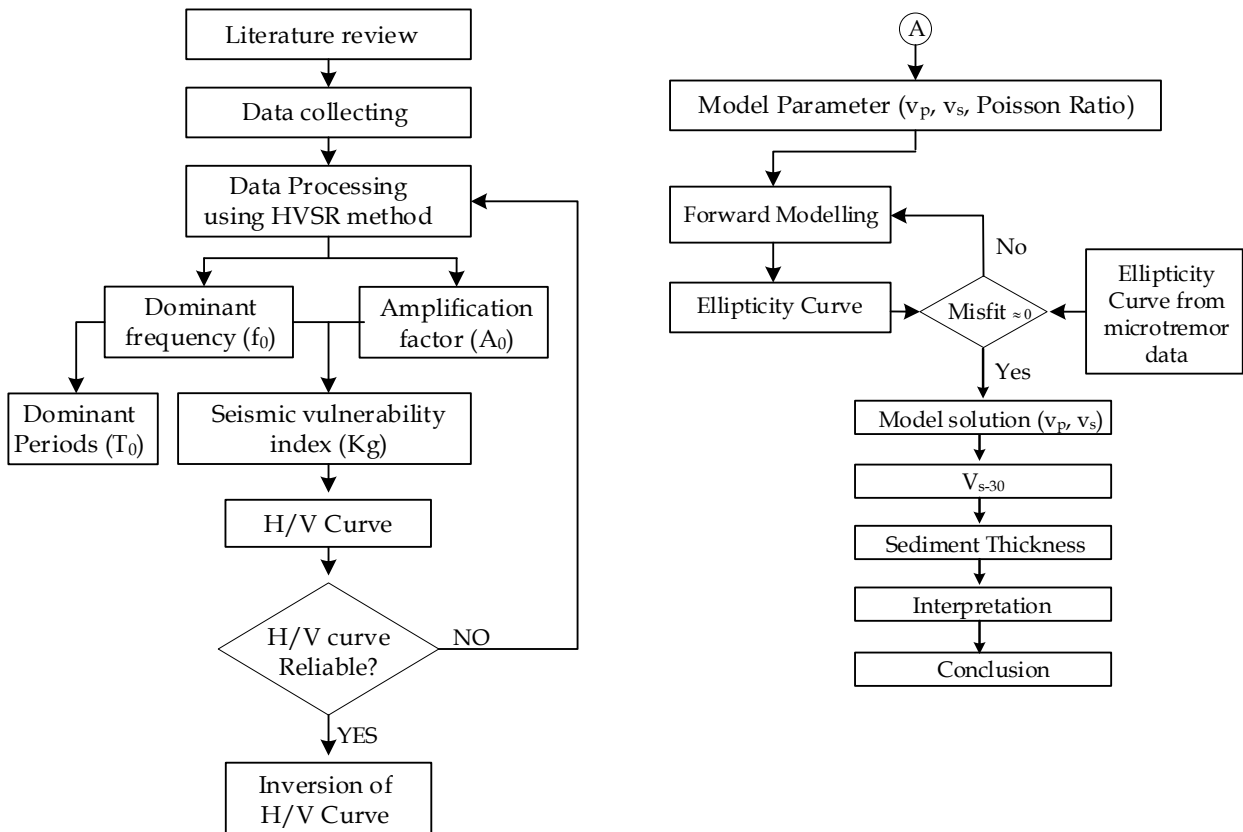

Figure 3. The research procedure

Result and Discussion

Microtremor measurements in the field are transient data of time-domain seismic signals in seismic records (seismograms). With the analysis using the Horizontal to Vertical Spectral Ratio (HVSR) method, data is obtained in the form of dominant frequency and amplification factor extracted from the H/V curve. In addition to these two parameters, the HVSR process can also analyze the subsurface characteristics that cause the local site effect during an earthquake and the site class based on the dominant period (T_0) and v_{s-30} in the study area.

The HVSR analysis results show the dominant frequency (f_0) distribution at 22 measurement points shown in Figure 4. The range of values for the dominant frequency is (0.8 - 18) Hz. Areas with high dominant frequency based on the classification Table 1 are included in type I, composed of the Kalibabak formation and the Lekopiko formation (Tuff rocky, lava breccia, and lava). The rocks in this formation have a high density and will suffer minor damage if an earthquake occurs. In general, based on Figure 4, the research area shows a low dominant frequency value. When viewed from the potential hazard of local site effects due to earthquakes, the research area shows unsafe conditions.
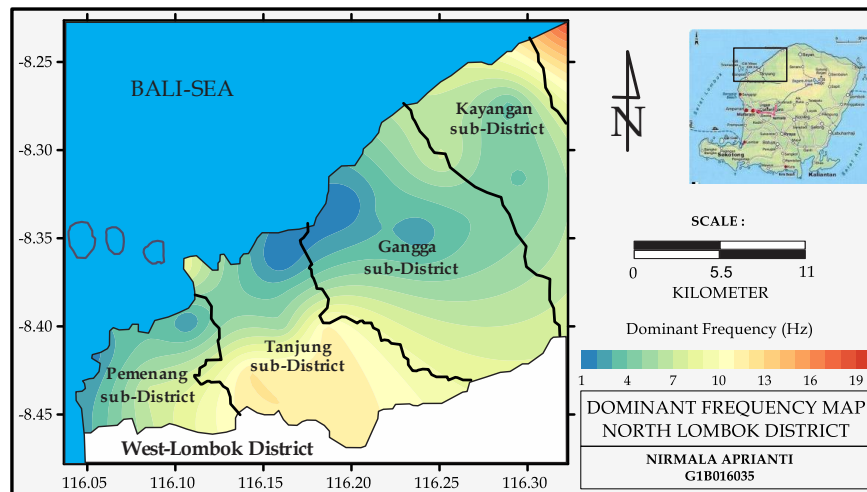

Figure 4. Map of Dominant Frequency Values

The amplification factor (A_0) in the form of a value distribution contour map has been overlaid with the North Lombok Regency administrative map shown in Figure 5.
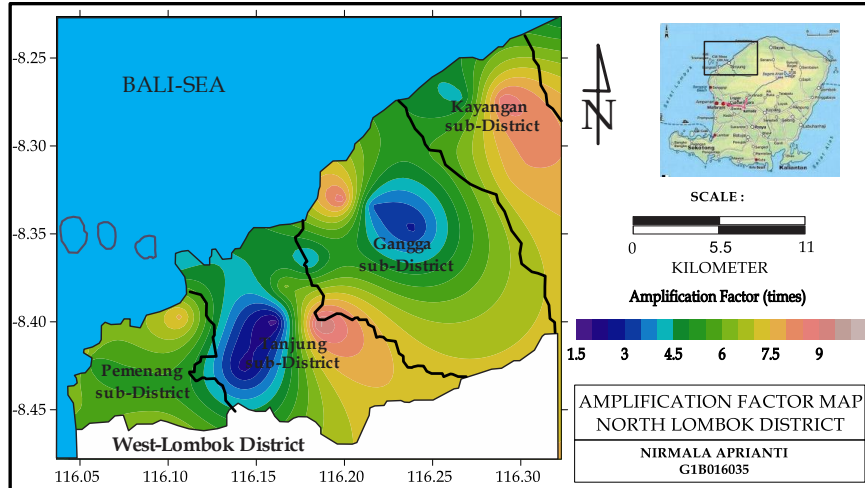
Figure 5. Map of Amplification Factor Value

The research area has an amplification factor (A_0) between (1.7 - 9.7). The low value is influenced by the high shear wave velocity (v_s) due to stony soil. These rocks indicate that the rocks in this area have a higher density than other regions, so that earthquake waves that pass through this region tend to experience smaller shock amplification.

In areas with a A_0 high value caused by a high impedance contrast, the density between layers is contrasting. This situation causes this area to have a softer soil hardness, resulting in bigger shocks to the buildings in this area. Above the surface, and causes the potential risk of an earthquake in this area to increase.

The sediment layer (d) in the study area was obtained [6.74 - 234.90] meters, and sediment thickness contours are shown in Figure 6.
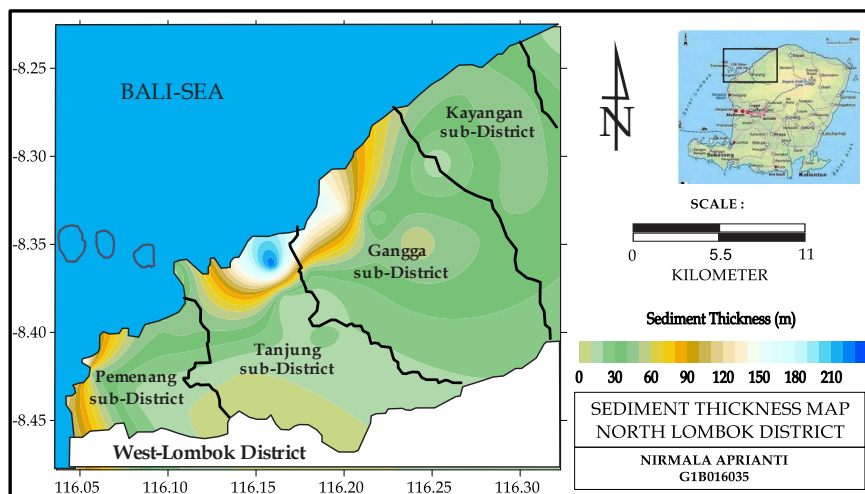

Figure 6. Map of the Distribution of Sediment Thickness Values

The center point towards the North of the coast has a thicker sediment thickness value compared to other areas in the study area. Geologically, this location is in a region with

alluvium deposits in the form of soft soil. The earthquake waves passing through this area will experience an increasingly large amplification of the earthquake waves, increasing the risk of damage due to the earthquake. Then in the south to the North of the study area, it was found that the value of the sediment thickness (d) was thinner than the other regions in the study location. The rocks that make up this area are the Kalibabak Formation deposits and the Lekopiko Formation, volcanic products with sedimentary rocks that are not compact and quickly escape. In this formation, the material consists of high-density materials, so that earthquake waves passing through this area will experience lower earthquake wave amplification. Sites with a thin layer of sediment tend to be safer with less risk of damage from earthquakes.

The seismic vulnerability index (Kg) value is influenced by the amplification factor and the research location frequency. The results of the seismic vulnerability index (Kg) are shown in **Figure 7**. This map shows that the seismic vulnerability index value ranges from (0.4 – 71.0) μs2/cm. The region with a low seismic vulnerability index value concentrated in the highlands or hilly areas. The hilly area has a solidified rock structure condition, which indicates it has a high-density value. It does not suffer significant damage caused by the earthquake. The region with medium to high seismic vulnerability index value is distributed along the coast, composed of alluvium deposits. It has a structure soft soil structure or has a low-density value. The seismic vulnerability index's high value makes the area vulnerable and can severely damage an earthquake.
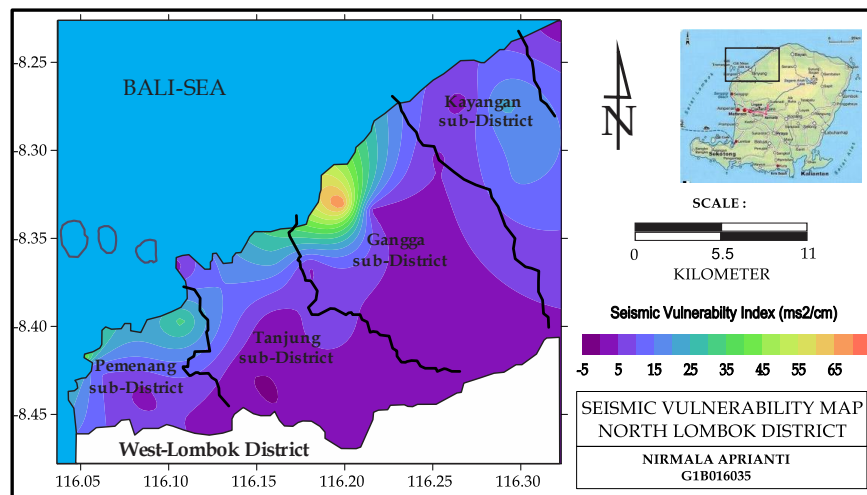

Figure 7. Map of Seismic Vulnerability Index Value

The distribution of the dominant period's value in the study area is 0.05 seconds to 1.2 seconds. Sites with a low (short) dominant period occurred in the south part of the study area. Based on table 3.5, these areas belong to site classes I class A and B. The rocks that make up this layer are the Kalibabak formation and the Lekopiko formation. Based on Zhao's classification, this area can experience low to moderate damage if an earthquake occurs. The value of the dominant period is shown in Figure 8 below:
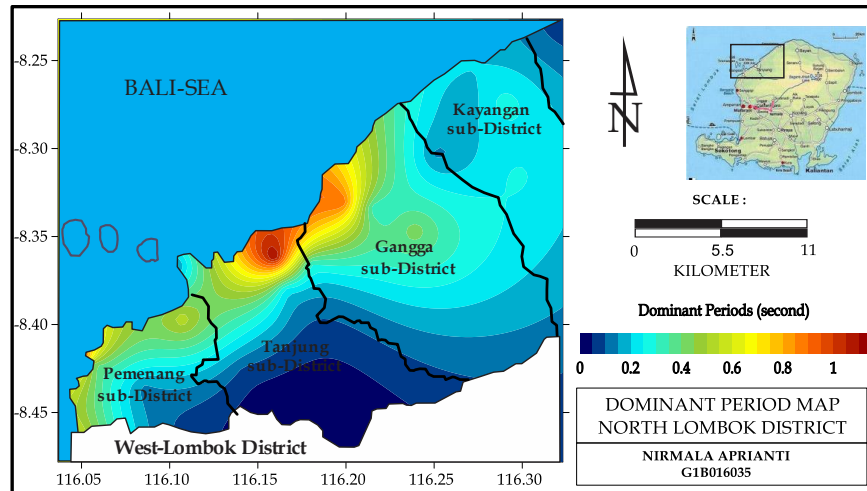
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Figure 8 Map of Dominant Period Value Distribution

The value of the dominant period of the moderate to high range (0.4 - 1.1) seconds occurs in the seaside area, which is included in the class D class III site. This area's location is on the edge beaches with alluvium formations and regions with lower elevations. Areas with high dominance periods have the characteristics of very soft constituent rocks located on the coast. It consisted of layers of alluvium and included in site classes IV class E. Based on the hardness level, the soft rock will have a more significant risk of earthquakes than areas in soil conditions that have hard constituent rocks.

A v_{s-30} is the average wave velocity up to a depth of 30 meters. The calculation uses equation 3.3. The result is the value of v_{s-30} between (20.05 - 287.04) m/s. The calculation results then plotted as shown in Figure 9.

The contour map shows that the research area is an area with a low v_{s-30} value. The research area included soil class D and E. Soil class D is composed of medium soil. Also, soil class E is composed of soft soil so that in this area, earthquake shocks will feel more substantial. On soft ground, earthquake waves will be trapped and cause a superposition between the waves.
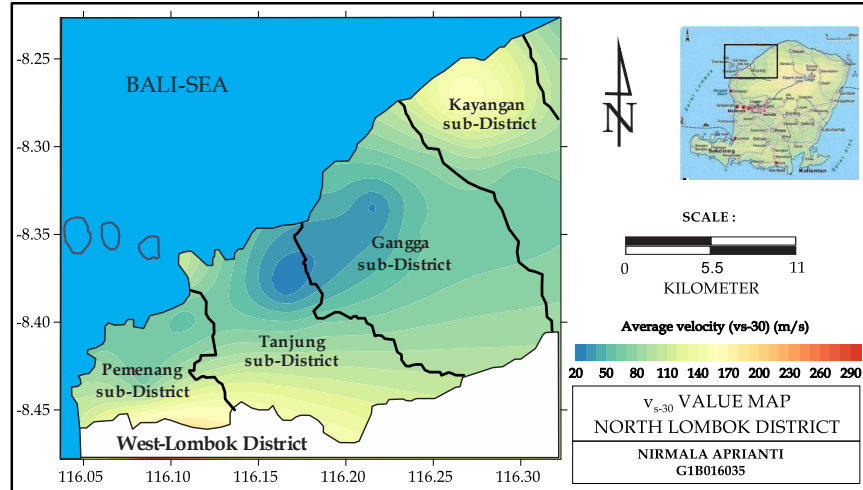
Figure 9. Value of v_{s-30} Contour Map

North Lombok Regency comprises quaternary deposits in young volcanic deposits (tuff, volcanic breccia, lava), which have experienced weathering and coastal alluvial deposits. The characteristics of the quaternary deposits tend to magnify earthquake shocks. In the Lekopiko Formation, on field observations, the rocks that make up this area are pumice tuff in partially weathered conditions, easily destroyed, very porous, with a layering structure.

Based on the values of dominant frequency (f_0), soil amplification (A_0), dominant period (T_0), v_{s-30}, the thickness of the sediment layer (d), and seismic susceptibility index (Kg), the research area is composed of alluvium rock composition. The subsurface layer is softer than the Kalibabak and Lekopiko rock formations sites with a harder level of solidity. The value of sediment thickness also affects the amplification of earthquake waves. Geologically, it is thicker in alluvium deposits so that earthquake waves passing through this area will experience a strengthening of earthquake waves and increase the risk of damage. The soil layer's characteristics included in the soft soil formed from the alluvium are classified as an earthquake-prone area.

The value of the v_{s-30} variable and the dominant period indicates that the area belonging to the class III class D site has moderate rock characteristics, at the measuring point of the coastal zone, which has a lower elevation, while the research area which includes in the class IV class site. E is a soft rock and causes an earthquake hazard. The thickness of the thicker sediment layer finds in softer rocks. It causes a higher level of earthquake risk vulnerability than the thickness of the thinner sediment layer.

Part of the study area is composed of soft alluvium rock and consisting partly of more hardened deposits. Soft sediment has a greater thickness than the more rigid layer. The more hardened layers are the Lekopiko and Kalibabak formations (consisting of tuff, pumice, breccia lava, and lava). These rocks will cause a greater risk of earthquakes than soil conditions with more rigid constituent rocks.

Conclusion

Based on microtremor analysis, the local site effect indicates that alluvium rocks caused more significant earthquake vibrations and more damage. Meanwhile, the Kalibabak and Lekopiko formations caused fewer earthquake vibrations and less wear. The research area is classified as Site Class IV class E and ranked as Site Class III class D based on the dominant period (T) and average velocity to a depth of 30 meters (v_{s-30}).

Acknowledgment

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