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Seismic Vulnerability Index Microzonation in Nagari Tanjung Alai, X Koto Singkarak Sub-District, Solok using HVSR Method

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Abstract: Nagari Tanjung Alai is located on the fault of the Indo-Nagari Tanjung Alai is located on the fault of the Indo-Australian plate and the Eurasian plate, which causes this area to become an earthquake-prone area. An earthquake occurs when the earth trembles or shifts abruptly as a result of tectonic plate movement, causing the rock strata on the earth's surface to shift. Earthquakes in the Nagari Tanjung Alai area pose serious problems; specifically, earthquakes threaten public safety, cause damage to infrastructure such as houses and roads, and trigger the movement of land masses which results in other disasters such as landslides and liquefaction. One method used to identify earthquake-prone areas is the HVSR (Horizontal Vertical Spectral Ratio) method.. One technique for analyzing microtremor data is the HVSR approach, which compares the vertical and horizontal components of the microtremor signal. The purpose of this research is to identify and map the microzonation of dominant frequency, amplification factor, and seismic vulnerability index in Nagari Tanjung Alai, X Koto Singkarak District, Solok Regency based on microtremor data processed using the HVSR method. This research is expected to contribute significantly to the understanding of earthquake disaster risk in the area. The HVSR technique of analysis reveals that the major frequency value falls between 0.5 Hz - 8.5 Hz, the amplification value ranges from 1.54 - 7.322, and The value of the seismic vulnerability index falls between 0.63312 to 107.223. Therefore, Nagari Tanjung Alai can be classified as having a high seismic vulnerability index.

Keywords: Amplification, Dominant frequency, HVSR, Microzonation, Seismic vulnerability index

1. Introduction

An earthquake is a shaking event caused by the sudden movement or displacement of rock layers in the earth's crust due to the faulting of tectonic plates or vibrations that occur on the surface due to the release of energy from within the earth. Earthquake waves are the result of the abrupt shifting

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of rock strata within the ground, which releases energy in all directions. When these waves hit the surface of the earth, their vibrations have the potential to harm all living and non-living objects, resulting in property damage and fatalities [1].

Solok Regency is one of the earthquake-prone areas in West Sumatra Province. In general, the Solok Regency area is close to the faults of the Indo-Australian plate and the Eurasian plate, the location of Solok Regency makes this area prone to earthquake disasters [2]. According to the West Sumatra Disaster Risk Assessment, the potential area exposed to earthquake hazards in Solok Regency is around 357,576 Ha with a low earthquake category of 110,668 Ha, a medium category of 152,213 Ha, and a high category of 94,695 Ha [3]. Nagari Tanjung Alai is an area located in Solok Regency, which has an area of about 30 km^2, located at coordinates 0°39'31 "S and 100°37'00 "E with an altitude of 400-1000 meters above sea level (masl). The population in Nagari Tanjung Alai reaches 2000 people. which is divided into 5 jorong namely Balai, Buah Jambu, Data, Koto Baru and Kubang data [4].

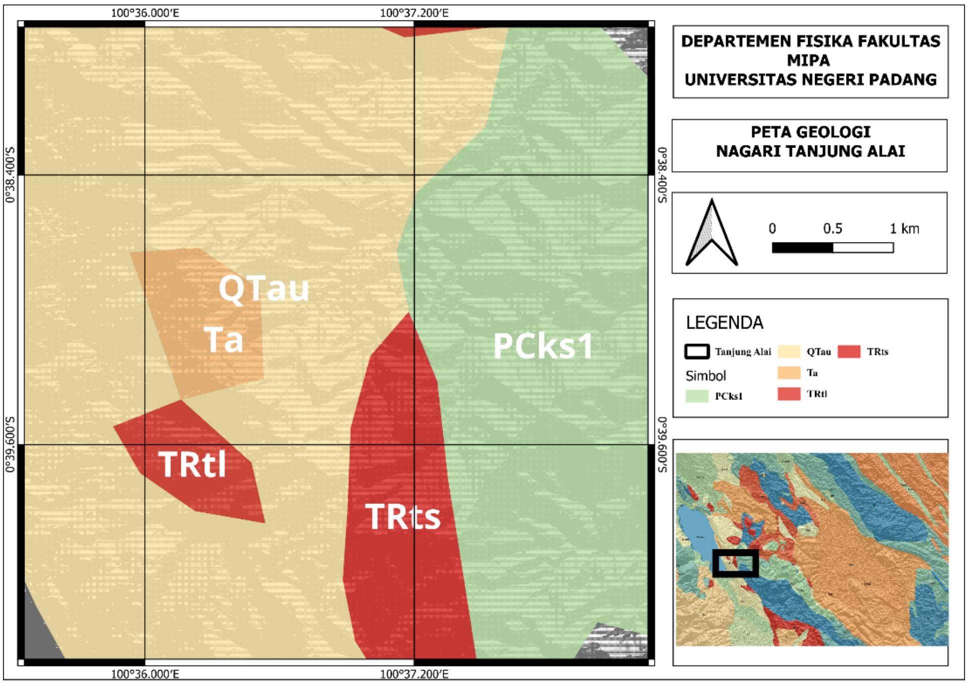

Figure 1. Geological Map of Solok Sheet

Stratigraphically, Nagari Tanjung Alai has geological characteristics influenced by tectonic conditions formed by the Sumatra fault. According to Figure 1 Geological Map, most of Nagari Tanjung Alai is composed of units consisting of unseparated volcanic rocks (Qtau) consisting of lava, conglomerate, and other colluvial deposits. Andesite to Basalt (Ta) rocks consist of lava flows, breccia, agglomerate, and hypabyssal rocks. The Batusabak and Serpih Members and the Batugamping (TRtl) Member consist of sandy limestone and K limestone. The Tuhur Formation (TRts) consists of sandstone, shale, sandy shale with intercalated rijang, radiolarite, black shale, and thin layers of metamorphosed grewak. The Phyllite and Shale Member of the Kuantan Formation (PCks) consists of shale and phyllite, with intercalations of sandstone, quartzite, siltstone, rijang, and lava flows.

Earthquakes in the Nagari Tanjung Alai area can face serious problems, especially earthquakes can threaten the safety of the community, earthquakes can cause damage to infrastructure such as houses and roads, worse earthquakes can trigger movement of land masses which results in other disasters such as landslides and liquefaction. Earthquakes cannot be known when and where they will occur. So the need for mitigation measures to reduce the impact of disasters or efforts to reduce victims is very necessary to be understood and carried out by all people who live around locations prone to natural disasters [5]. Therefore, it is very important to mitigate earthquakes in Nagari Tanjung Alai to reduce the risk due to earthquakes.

One way of mitigating disasters that can be applied is by identifying areas with earthquake potential. This identification process can be done using geophysical methods. Some geophysical methods that are relevant to be used in this case are microtremor [6]. Using the Horizontal to Vertical Spectral Ratio (HVSR) approach, a research called microtremor may be conducted to ascertain the geological characteristics of a region [7]. The HVSR method is one of the easiest and least expensive techniques to determine the structure of the subsurface layer without causing disturbance to the structure [8]. The HVSR method is a passive seismic method that utilizes natural environmental noise. This method involves comparing the spectrum ratio between microtremor signals in the horizontal and vertical components [9]. The HVSR method can determine the dominant frequency value which states the material composition that dominates an area and the amplification factor value which states the wave magnification experienced by an area [10]. The dominant frequency and amplification factor are used to find the value of the seismic vulnerability index used for analyzing potential earthquake areas.

2. Materials and Method

The type of research used in this study is qualitative research. The data obtained are data from direct measurements in the area under study to obtain data on dominant frequency, amplification and seismic vulnerability. This data was obtained using the Microtremor method in the Nagari Tanjung Alai area, X Koto Singkarak District, Tanah Datar Regency. Microtremor data were collected at 17 points with a distance of 500 meters between points can be seen in Figure 2.

This research uses research instruments and materials consisting of hardware and software. The hardware used consists of 3D-MAE Seismograph, Seismatrack-MAE, S3S Type Seismometer, Connecting Cable, Compass, GPS, Laptop and the software used consists of Easy HVSR Software, Google Earth Pro, Qgis, Microsoft Excel. Microtremor measurement data is obtained in the form of primary data. The microtremor data collection technique used refers to the standards set by the SESAME European Research Project2004 [11]. After that, the microtremor data obtained was processed using the HVSR method, HVSR data processing was carried out using Easy HVSR software.

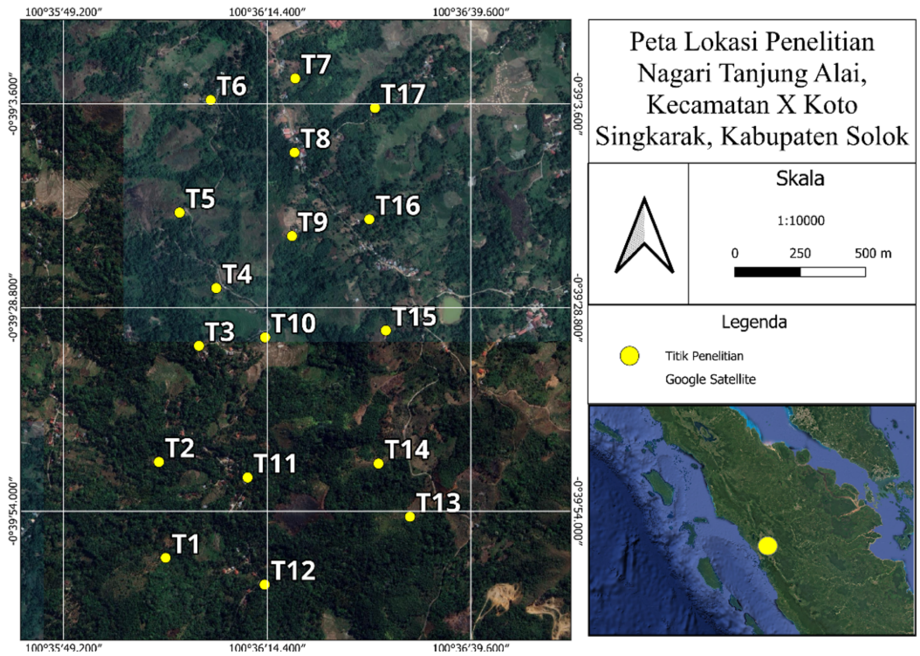

Figure 2. Research Point

Processing of microtremor data in Easy HVSR software begins with entering the microtremor recording file, then a filtering process is carried out using a low pass filter to retain low frequency signals and dampen signals with frequencies above the cut-off value, generally set at 20 Hz. This process is adjusted to the characteristics of microtremor signals that are dominant at low frequencies. Next, windowing is performed using a Hanning window that functions to divide the signal into several segments (windows) with smooth amplitude transitions at both ends to minimize spectral leakage. Then, Fourier transformation is performed on the North-South (NS), East-West (EW), and Vertical (V) direction signal components to obtain the Fourier spectrum of each window. The spectrum of the horizontal component is averaged by the root mean square, and then divided by the spectrum of the vertical component to produce an H/V curve. Before that, To improve the stability of the resultant H/V curve, the amplitude spectra of the three components were first smoothed using the Konno-Ohmachi smoothing function. Based on the curve's greatest peak, the dominant frequency and soil spectrum amplification factor may be determined from this H/V curve. The data processing findings yielded the seismic vulnerability, amplification, and dominant frequency values.

The dominant frequency value is a reflection of the physical condition of the soil, namely the thickness or thinness of the subsurface sediment layer of an area. The dominant frequency is inversely proportional to the thickness of the sediment (bedrock) and directly proportional to the average velocity. In areas that have a thicker sediment layer will tend to have a smaller dominant frequency value [12]. The dominant frequency value from HVSR processing states the natural frequency found in the area. This states that if there is an earthquake or disturbance in the form of vibration that has the same frequency as the dominant frequency, there will be resonance resulting in amplification of seismic waves in the area [13]. The dominant frequency in the Nakamura technique is a function of shear wave velocity and sediment layer thickness [6]. This relationship is derived from the principle of shear wave resonance in a single layer, where resonance occurs when the layer thickness is equal to a quarter wavelength ($\lambda/4$). By substituting the wave equation $\lambda = V_s/f_0$, it is obtained:

$$f_0 = \frac{V_s}{4h} \tag{1}$$

This equation shows that f_0 (dominant frequency) is directly proportional to V_s (shear wave velocity) and inversely proportional to h (layer thickness).

Table 1. Classification of Soils Based on Dominant Frequency Values.

Soil Classification	Dominant Frequency	Description
Type I	6,667< $f_0 \leq$ 20 Hz	The surface sediment layer is very thin. (<5 m)
Type II	4 < $f_0 \leq$ 6,67 Hz	category Sedimentary layers Surface medium (5–10 m)
Type III	2,5< $f_0 \leq$ 4 Hz	Showing thick surface sediment layers (10–30 m)
Type IV	f_0< 2,5 Hz	Showing very thick surface sediment layers (>30 m)

(Source: Siburian,2024[13])

Amplification is the process by which seismic waves are magnified as a result of notable variations in soil layers. That instance, as seismic waves go from a harder medium to a softer one, their magnitude will rise. The wave's magnification increases with the degree of difference between the two layers' properties [15]. If the soil or rock layer has experienced deformation (weathering, folding, and displacement) that alters the rock's composition, the amplification factor value may rise. The degree of deformation in the rock body's weathering can affect the amplification value inside the same rock [16].

The amplification factor (A_0) in the Nakamura technique represents the ratio of the dynamic properties of bedrock and sedimentary layers. Through the assumption of similar density of bedrock and sedimentary rock (ρ_b=ρ_s), the amplification expressed as the ratio of shear wave velocity of bedrock to sediment can be formulated as follows:

$$A = \frac{v_b}{v_s} \tag{2}$$

A is the amplification,v_b the speed of bedrock wave propagation,v_s the speed of soft rock wave propagation. The amplification value indicates that the surface layer is more soft than the bedrock, thus amplifying the ground motion. According to Poudyal, 2024 amplification factor values can be grouped into four classifications, as shown in Table 2 [16]:

Table 2. Classification of Amplification Factor Values

Classification	Amplification Factor Values
Very Low	A0 < 1,6
Low	1,6 < A0 ≤ 2,7
Medium	2,7 < A0 ≤ 5,4
High	5,4 < A0 ≤ 6,67
Very High	A0 > 6,67

(Source: Poudyal, 2024)

The seismic susceptibility index can indicate the vulnerability of an area affected by shaking or movement of rock layers. The higher the seismic susceptibility index of an area, the more vulnerable the area is to shaking [17]. A high vulnerability index value can be achieved by combining high amplification values and low frequency values [6]. The seismic susceptibility index is useful for predicting weak zones at the ground surface during an earthquake. The seismic susceptibility index is calculated by multiplying the peak of the HVSR spectrum by its predominant frequency [6]. The susceptibility value (Kg) can be found by the equation:

$$Kg = \frac{{A_0}^2}{f_0} \tag{3}$$

Description:

Kg = Seismic susceptibility index

Ao^2= Amplification factor

fo = Dominant frequency (Hz)

According to Akkaya, the 2020 seismic vulnerability index values are categorised as follows, as shown in Table 3 [18].

Table 3. Classification of Seismic Vulnerability Index

Classification	Seismic Vulnerability Index
Low	$Kg \leq 3$
Medium	$3 < Kg \leq 5$
High	$5 < Kg \leq 10$
Very High	$Kg > 10$

(Akkaya, 2020 [18])

Based on the problems that have been described, this study aims to identify and map the microzonation of dominant frequency, amplification factor, and seismic vulnerability index in Nagari Tanjung Alai, X Koto Singkarak District, Solok Regency based on microtremor data. Earthquake disaster mitigation can be done by knowing the areas prone to earthquakes. This research is expected to make a significant contribution to the understanding of earthquake disaster risk in the area.

3. Results and Discussion

This research was conducted in Nagari Tanjung Alai, X Koto Singkarak District, Solok Regency. Microtremor data were collected using a set of sysmatrack MAE seismograph tools and processed using easy hvsr software. Microtremor data was measured with three components of North-South, East-West and Vertical, utilizing the horizontal vertical spectral ratio (HVSR) method. From the data, H/V curves were obtained which contain information on dominant frequency, amplification, seismic susceptibility. The values of dominant frequency, amplification, and seismic susceptibility can be seen in Table 4.

Table 4. Dominant Frequency, Amplification, and Seismic Susceptibility values

Point	Frequency Dominant	Amplification	Susceptibility Seismic
T1	1.9	3.45	6.264474
T2	8.95	2.7	0.814525
T3	2.35	3.82	6.209532
T4	2.95	1.98	1.328949
T5	0.7	1.544	3.405623
T6	4.45	2.74	1.687101
T7	2.65	3.86	5.622491
T8	2.65	3.24	3.961358
T9	2.65	3.2	3.864151
T10	2.8	3.74	4.995571
T11	9.25	2.42	0.633124
T12	0.5	7.322	107.2234
T13	2.5	6.96	19.37664
T14	2.65	5.91	13.18042
T15	2.5	4.88	9.52576
T16	1.7	2.42	3.444941
T17	3.25	2.55	2.000769

3.1 Dominant frequency

Thick sediment layers are found in places with low dominant frequency values, whereas thin sediment layers are found in areas with high dominant frequency values. Stated differently, a high dominant frequency value indicates that hard rock makes up the subsoil. Additionally, soft rocks (sedimentary rocks) make up the subsurface if the dominant frequency value is low. The thickness of the sedimentary layer and the subsurface velocity have an impact on the prevailing frequency. If it passes through a soft medium, the subsurface velocity will be low because the soft medium can reduce the wave velocity's travel time [17]. Therefore, areas with dominant frequencies are prone to earthquakes.

Based on Table 4, the dominant frequency value in the research region of Tanjung Alai Regency, X Koto Singkarak District, and Solok Regency, the predominant frequency value ranges from 0.5 Hz-8.5 Hz with the lowest value at research point T5 and the highest value at research point T2 with the lowest value being at research point T5 and the highest value being at research point T2. The research area is dominated by soil types III and IV with a range of values < 4 Hz, the following interpolated map form of the dominant frequency value is shown in Figure 3.

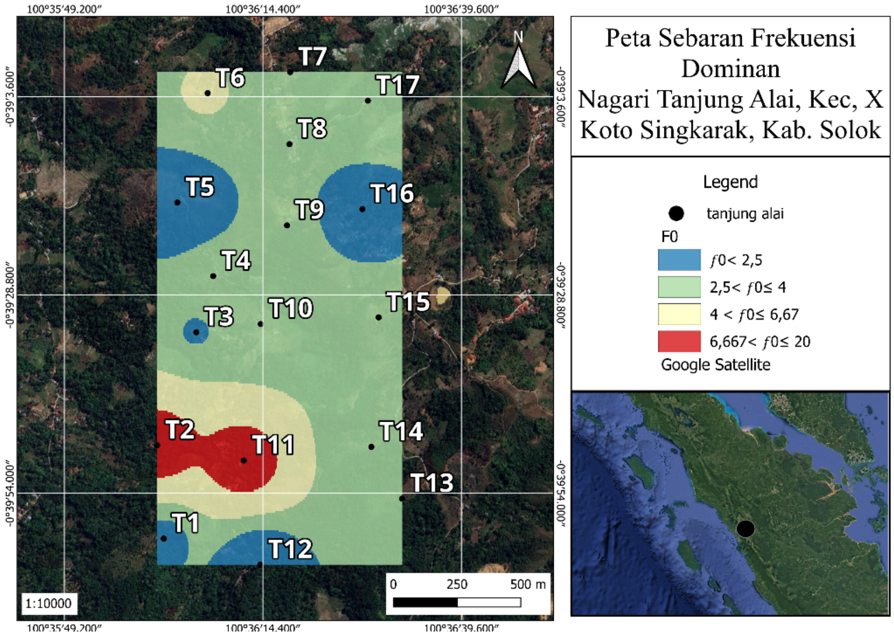

Figure 3. Interpolation map of dominant frequency

The results of HVSR data processing obtained the dominant frequency value from the peak of the H/V curve. The dominant frequency value in the study area shows a fairly diverse variation in the thickness of the surface sediment layer. The frequency value ranges from 0.5 Hz to 9.25 Hz, with the most frequently occurring value in the range of 2.5 Hz. Based on the classification of soil layer thickness in Table 1, the measurement results are divided into four main categories. The thin surface sediment layer category (8.95 Hz – 9.25 Hz) was identified at points T2 and T11. The high dominant frequency values at these two locations indicate that the surface sediment layer above the bedrock is relatively thin (<5 metres). The second category is the medium surface sediment layer (4.45 Hz) at point T6, indicating a surface sediment thickness ranging from 5 to 10 metres. The third category is a thick surface sediment layer (2.5 Hz – 3.25 Hz) identified at points T4, T6, T7, T8, T9, T10, T13, T14, T15, T17, indicating that these points have an estimated surface sediment thickness of 10 to 30 metres. The fourth category consists of very thick surface sediment layers above 30 metres found at points T1, T3, T5, T12, T16.

Based on the dominant frequency value of the study area, it is dominated by low frequency values, indicating that the study area has a sediment layer thickness of more than 30m. This is in line with the opinion of Yogaswara and Kuncahyani that areas with low dominant frequency values have thick sediment layers, thin sediment layers are present in areas with high dominant frequency values [17]. Stated differently, a high dominant frequency value indicates that hard rock makes up the subsoil. Soft rocks, or sedimentary rocks, make up the subsurface if the prevailing frequency value is low. Therefore, Nagari Tanjung Alai is a vulnerable area in the event of an earthquake.

3.2 *Amplification*

The process by which seismic waves that arise from notable variations in soil layers enlarge is known as amplification. That instance, as seismic waves go from a harder medium to a softer one, their magnitude will rise. The wave's magnification increases with the degree of difference between the two layers properties [15].

Table 4 is the value of the amplification factor at each research point in Tanjung Alai Regency, X Koto Singkarak District, Solok Regency obtained amplification values varying from 1.54 - 7.322. The following interpolation map of the amplification factor value can be seen in Figure 4.

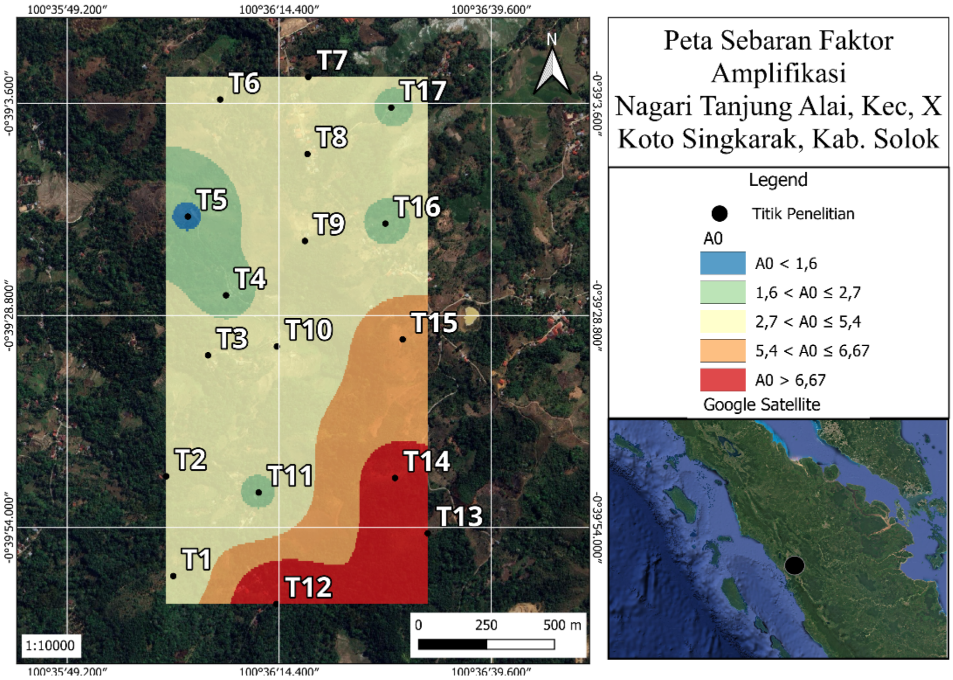

Figure 4. Amplification interpolation map

Table 4 shows the amplification factor values at each research point in Nagari Tanjung Alai, X Koto Singkarak District, Solok Regency, with amplification values varying from 1.54 to 7.322. The interpolation map of the amplification factor values can be seen in Figure 4. The amplification values were also obtained from the H/V curve peak along with the dominant frequency values. The amplification values obtained varied at each research point with a range of 1.54–7.322. The low amplification value category, with a range of 1.98–2.42, was found at research points T4, T11, T16, and T17. The medium amplification factor value ranged from 2.7 to 4.88 at research points T1, T2, T3, T6, T7, T8, T9, T10, and T15. The high amplification factor value was 5.91 at research point T14. Finally, the very high category, with a range of 6.96–7.32, was found at research points T12 and T13.

Based on the amplification values, of soft rocks. This is in line with Nakamura's (1989) assumption that if the soil or rock layer has experienced deformation (weathering, folding, and displacement) that alters the rock's composition, the amplification factor value may rise. The degree of deformation in the weathering of the rock body can affect the amplification value within the same rock.

3.3 Seismic Vulnerability

The seismic vulnerability index (Kg) has the ability to be utilized determine the level of vulnerability and potential damage to land movement [17] . From the value of the dominant frequency and amplification, the seismic vulnerability index (Kg) is obtained by using Equation 3 and classification based on Table 3 so that the seismic vulnerability index value analysis is shown in Table 4.

Table 4 is the result of data processing of the soil susceptibility index which has a range of values from 0.63312 - 107.223. The following is a seismic vulnerability interpolation map based on the analysis of the seismic vulnerability index values as shown in Figure 5.

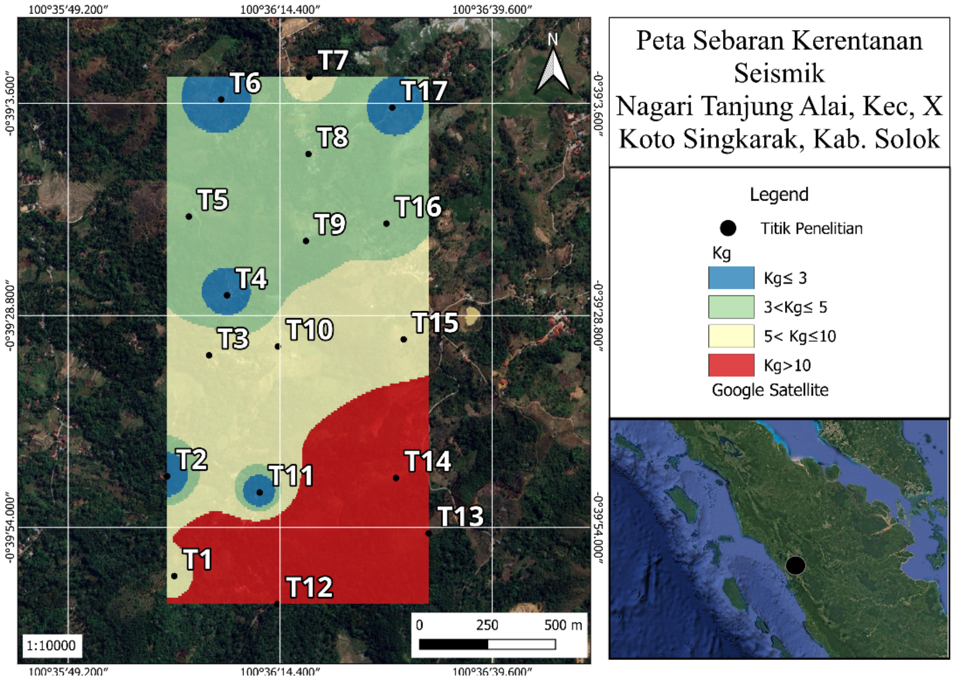

Figure 5. Seismic vulnerability interpolation map

The interpolation map of seismic vulnerability microzonation results presented in Figure 5 shows the distribution of vulnerability levels in the study area, which are classified into four categories. The low category (0.63-2.00) is distributed at points T2, T4, T6, T11, and T17. This condition indicates that the area has relatively stable and compact soil layers. The medium category (3.41–4.99), which covers points T5, T8, T9, T10, and T16, indicates a medium level of risk that still needs to be watched. The high category (5.62–9.52) is found at points T1, T3, T7, and T15, indicating a level of risk that needs to be watched very closely. The Very High category (13.1 - 107.22) is found at research points T12, T13, T14. These areas require special attention as they are more vulnerable to movement damage.

Based on the seismic vulnerability index values in the study area, it is dominated by low and high seismic vulnerability indices. This indicates that the research area is vulnerable to impacts due to shaking or ground movement. In line with Yogaswara and Kuncahyani stated that the seismic susceptibility index can indicate the vulnerability of an area affected by shaking or movement of rock layers [17]. The higher the seismic vulnerability index of an area indicated, the more vulnerable the area is affected by shaking.

4. Conclusion

Based on research conducted in Nagari Tanjung Alai, X Koto Singkarak District, Solok Regency, it can be concluded that the dominant frequency obtained ranges from 0.5 Hz - 9.25 Hz, the amplification value is obtained with a value range of 1.54 - 7.322 and the seismic vulnerability index value at the research point ranges from 0.63312 - 19.37664, there is one largest with a value of 107.2234.

Thus it can be concluded that the seismic vulnerability index in Nagari Tanjung Alai, X Koto Singkarak District, Solok Regency can be classified as including areas that have a high seismic vulnerability index.

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