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Identification of Landslide-Prone Areas in Bukik Lantak Timpeh Subdistrict Dharmasraya Regency Using the HVSR Method

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Abstract: Landslides are natural disasters caused by the downslope movement of soil or rock masses due to slope instability. Timpeh District in Dharmasraya Regency is among the areas frequently affected by landslides; therefore, a study was conducted using the microtremor method with the Horizontal to Vertical Spectral Ratio (HVSR) approach in Bukik Lantak to assess vulnerability levels. The analysis focused on dominant frequency, amplification factor, and seismic vulnerability index, which are important for characterizing subsurface conditions and soil response, as well as shear wave velocity (Vs), which was used to evaluate soil strength and slope stability. The results showed that the dominant frequency ranged from 0.1 to 9.55 Hz, amplification factor from 1.11 to 4.12, seismic vulnerability index from 0.3052 to 15.376, and Vs from 120 to 1,800 m/s. Areas with low dominant frequency, low Vs, high amplification factor, and high seismic vulnerability index were categorized as having higher landslide susceptibility. Based on these criteria, observation points TP1, TP3, TP5, TP7, TP15, and TP16 were identified as highly vulnerable, indicating that the microtremor method can serve as a valuable reference for landslide susceptibility assessment and disaster mitigation efforts in the study area.

Keywords: Landslide, Micotremors, HVSR, Timpeh Subdistrict

1. Introduction

Landslides are natural disasters that occur when soil or rock moves downslope. Landslides are caused by disturbances in the stability of the soil or rocks that form slopes [1]. In Indonesia, the high frequency of landslides is attributed to its many hilly regions with steep slopes. Additionally, the tropical climate results in high rainfall in most parts of Indonesia, which is also a contributing factor to landslides.

Dharmasraya Regency is generally a hilly and mountainous area with a topography ranging from 100 to 2,600 meters above sea level. One of the areas in Dharmasraya Regency that has experienced

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landslides is the Bukik Lantak area, located in Nagari Tabek, Timpeh Subdistrict, Dharmasraya Regency, West Sumatra. Bukik Lantak is an area with hilly topography that has steep slopes with slope heights ranging from 350 m to 800 m, making it geomorphologically prone to landslides, especially during the rainy season or when soil stability is disturbed. The lithology of this area consists of four rock units: a meta-tuff unit belonging to the Carboniferous-aged Kuantan Formation, a limestone unit with quartzite interbeds, a tuff unit part of the Lower Telisa Group of Miocene age, and an alluvial unit. The geological structure of this area consists of normal faults and strike-slip faults with a general northwest–southeast orientation [2].

One landslide occurred on January 24, 2024, disrupting the road and traffic connecting Timpeh District and Pulau Punjung. This shows that this area has a potential for disasters that need to be watched out for. If not handled properly, human activities such as construction and tourism development can weaken soil conditions, increasing the risk of landslides in the future.

Efforts to minimize the impact of landslides involve disaster mitigation. One way to mitigate disasters is to identify areas prone to landslides. Identification is carried out using the microtremor method. The microtremor method is a method based on the dominant frequency value of the soil and amplification factors, resulting in a soil vulnerability index value that can be processed using the HVSR (Horizontal to Vertical Spectral Ratio) method to determine the soil layer structure. Microtremor measurements play a significant role in disaster mitigation efforts, both for earthquakes and landslides [3]. Microtremor measurement is a passive seismic measurement to record vibrations generated by earth activity or human activity. This method is usually used to estimate the level of damage caused by earthquakes and can also be used to determine the condition of underground structures based on their dominant frequency and amplification factors [4].

Data obtained from the microtremor method consists of natural vibrations (ambient noise) originating from natural sources and human activities [5]. After that, microtremor analysis is performed using the HVSR (Horizontal to Vertical Spectral Ratio) technique [6]. Microtremor data processing can utilize the HVSR method to generate dominant frequency and amplification parameters. Then, both sets of data are used to determine the seismic vulnerability index and shear wave velocity, which serve as parameters for analyzing areas prone to landslides.

2. Materials and Method

This study used quantitative methodology. The research was conducted in Bukik Lantak, Timpeh District, Dharmasraya Regency, as shown in Figure 1. The data obtained is data from direct measurements in the area under study.

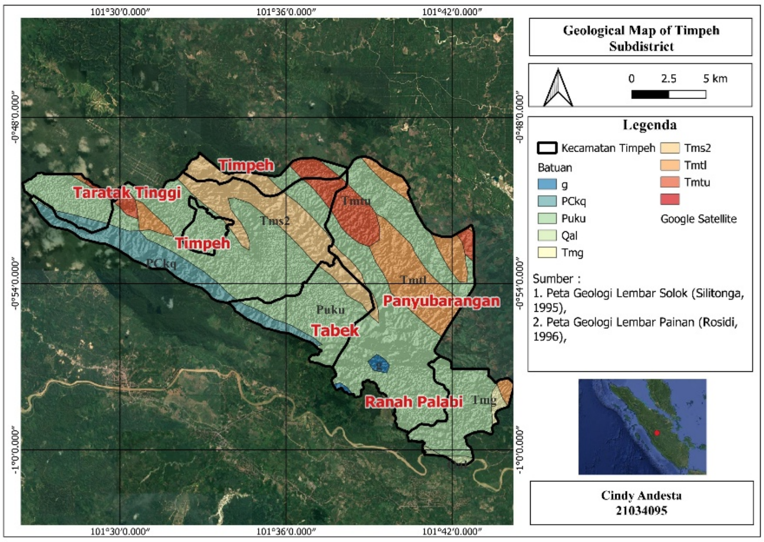

Figure 1. Research Location Map

Microtremor data collection consists of 16 measurement points, with a distance of ± 400 m between each point, as shown in Figure 2. At every data collection point, the acquisition process takes 20-40 minutes and uses a sampling frequency of 200 Hz [7]. Sysmatrack - MAE is a device that records ground vibrations caused by natural sources and rocks during data acquisition. The S3S-type seismometer is an instrument designed to detect and record ground vibrations caused by earthquakes, equipped with measurement time information. Additionally, the equipment used consists of a laptop, connecting cables, GPS, and a compass. The acquired data is recorded as signal data in *SAF format [8].

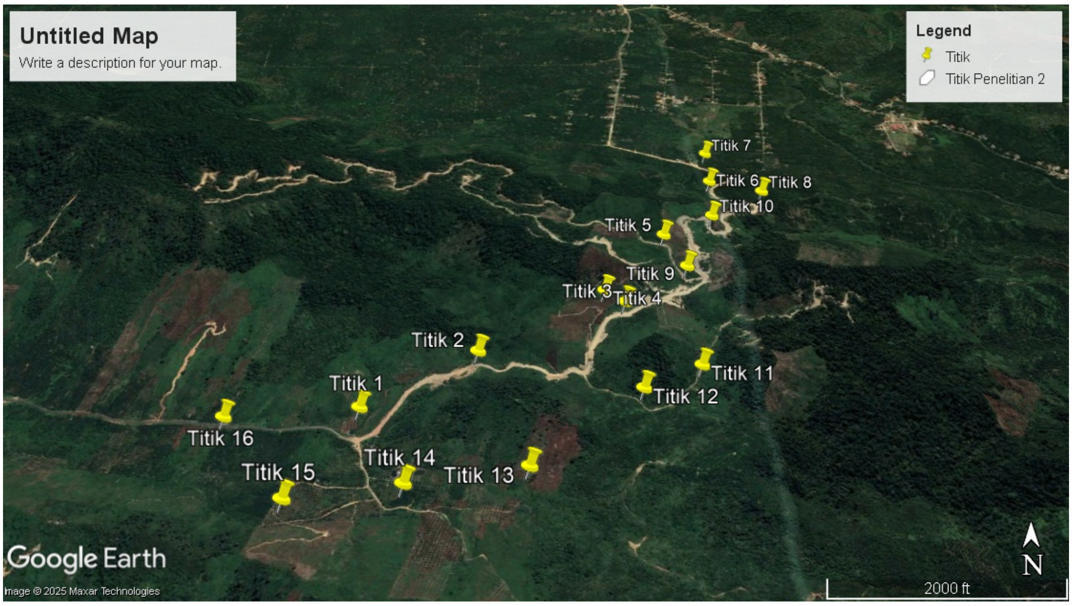

Figure 2. Microtremor Measurement Point at Bukik Lantak

After collecting data on microtremors, the Easy HVSR software applied the HVSR method to analyze the results. This processing yields a H/V curve, which can reveal the research point's dominant frequency and amplification factor. A variety of sources, including wind, traffic, and human activity, can cause tiny, continuous vibrations in the ground known as microtremors.

Earthquakes, whether caused by nature or humans, can reveal interesting information about a region's geology through microtremors. When it comes to estimating the risk levels associated with seismic activity, the microtremor method is both suitable and accurate because it can determine the characteristics of soil layers based on dominant frequency and amplification. [9].

You can estimate the ratio of the vertical component to the horizontal component's Fourier spectrum and use it to perform the HVSR (Horizontal to Vertical Spectral Ratio) method. A local geological amplification value is represented by the HVSR ratio at the dominant frequency, which is equal to the frequency at the first HVSR peak; the dominant frequency is also known as the local dominant frequency. The dominant frequency and amplification are the key parameters that the HVSR method produces. [7] and can be formulated in equation (1).

$$H/V = \frac{\sqrt{(S-NS)^2+(S-EW)^2}}{S-V} \quad (1)$$

Where H/V represents the HVSR ratio's spectrum, S-EW represents the horizontal component's spectrum in the east-west direction, S-NS represents the component's spectrum in the north-south direction, and S-V represents the component's spectrum in the vertical direction. [10].

Microtremor data processed using the HVSR method yields supporting parameters, including dominant frequency, amplification factor, and shear wave velocity. Dominant frequency is a parameter that can describe soil conditions, as the value of dominant frequency at a certain depth can be correlated, as it can reflect a wave beneath the surface [4]. The dominant frequency affects shear wave velocity and sediment layer thickness. Shear wave velocity is one of the most important dynamic soil parameters in soil classification and site response analysis [11].

Amplification is a variation in seismic wave magnitude caused by significant differences in material types between subsurface layers [12]. The properties of horizontal signals with vertical signals will be proportional to the increase in waves when passing through a medium [13]. The parameter indicating the level of vulnerability to earthquakes based on subsurface conditions in an area is called seismic susceptibility index for earthquakes (K_g). The seismic susceptibility index value is influenced by the impact caused [14]. The seismic vulnerability index's value varies from region to region, as it is influenced by amplification factors (A_0), and dominant frequencies (f_0)as shown in equation (2).

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

This is where the dominant frequency (f_0) and amplification factor (A_0) come into play. An area's susceptibility to deformation can be revealed by the seismic vulnerability index. One way to assess the susceptibility and possible harm caused by land movement is through the use of the seismic vulnerability index (K_g). The magnitude of the dominant frequency (f_0) and the amplification factor (A_0) determine the magnitude of the seismic vulnerability index (K_g). There is a direct correlation between the sediment layer thickness (h) and the seismic vulnerability index (K_g). An area's thin sediment layer corresponds to a low seismic vulnerability index (K_g). [10]. Table 1 shows the classification of Kg values.

Table 1. Classification of Seismic Vulnerability Index values

Zone	Classification	Value Kg
1	Low	Kg<3
2	Medium	3<Kg<6
3	High	Kg>6

3. Results and Discussion

The results obtained from this study are the dominant frequency value (f_0), amplification factor (A0), seismic vulnerability index (K_g), and shear wave velocity (Vs) in Bukik Lantak, Timpeh Subdistrict.

3.1 Dominant Frequency (f_0)

The dominant frequency is the natural frequency or the frequency that occurs in a particular area. The value of the dominant frequency describes the characteristics of the sediment layer conditions. Areas composed of thick sediment layers have a high level of vulnerability to landslide hazards, as sediment layers are prone to deformation or mass movement of soil [15]. From the data processing, it was found that the dominant frequency values in Bukik Lantak, Timpeh Subdistrict, ranged from 0.1 Hz to 9.55 Hz. The distribution of dominant frequency values, which is based on the measurement points, can be divided into four types of soil, as depicted in Table 2 below:

Table 2. Classification of Dominant Frequency Values in Buki Lantak, Timpeh Subdistrict

Research Focus	Type	Kind	Dominant Frequency Value	Classification	Description
TP2, TP4, TP11, TP13	Type IV	Kind I	6.7-9.55	Rocks of gravel, hard sandy, etc. Tertiary age or older.	Dominated by hard rocks, the sedimentary thickness of the surface is very thin.
TP3, TP6, TP9	Type III	Kind II	5.65-6.25	Sandy-gravel, loam, sandy hard clay, etc. Alluvial rocks with a thickness of about 5 m.	The sediment thickness of the surface is about 5-10 m, categorised as medium.
TP5, TP7, TP8, TP10, TP14, TP16	Type II	Kind III	2.5-3.85	Rocks of sandy hard clay, sandy-gravel, etc. Alluvial rocks with thickness > 5 m.	The thickness of the surficial sediments is about 10-30 m.
TP1, TP12, TP 15	Type I	Kind IV	0.1-0.7	Alluvial rocks from delta sedimentation, top soil, mud, etc. With thickness ≥ 30 m.	The sedimentary thickness of the surface is very thick.

Based on Table 2, the distribution of dominant frequency values is categorized into four soil types according to Kanai's classification [10]. Dominant frequency values ranging from 0.1 Hz to 0.7 Hz are classified as soil type IV. The presence of soft layers or thick alluvial deposits is generally reflected in areas with low f0 values and tend to have higher amplification potential. This aligns with the Kanai classification, where dominant frequencies <2.5 consist of soft materials, such as alluvial rocks from delta sedimentation, topsoil, and mud with extremely thick sediment layers. In soft soil conditions or low f0 values, the duration of seismic waves passing through the soil is longer and experiences greater amplification, resulting in significant shaking and high levels of damage.

The dominant frequency is moderate, with values ranging from 2.5 Hz to 6.25 Hz. Areas with moderate f0 values typically have denser soil layers or have undergone natural compaction processes, such as stiff clay or dense sand. This aligns with Kanai's classification, where areas with f0 values from 2.5 Hz to 6.67 Hz are categorized as Soil Type II and Soil Type III, which include alluvial rock, sandy gravel, sandy hard clay, clay, and loam.

Meanwhile, the dominant frequency with high values ranges from 6.67 Hz to 9.55 Hz. Areas with these values indicate very hard soil characteristics, or even bedrock that is relatively shallow from the surface. This is consistent with Kanai's classification, where soil with a frequency of 6.67 Hz – 20 Hz is classified as Type I soil, consisting of hard rock, hard gravel sand, and soil classified as tertiary soil. In areas with high f0 or hard soil conditions, the duration of seismic waves passing through the soil becomes shorter, resulting in smaller shaking and lower damage levels. The following map shows the distribution of dominant frequency values in Bukik Lantak, Timpeh Subdistrict, as illustrated in Figure 2.

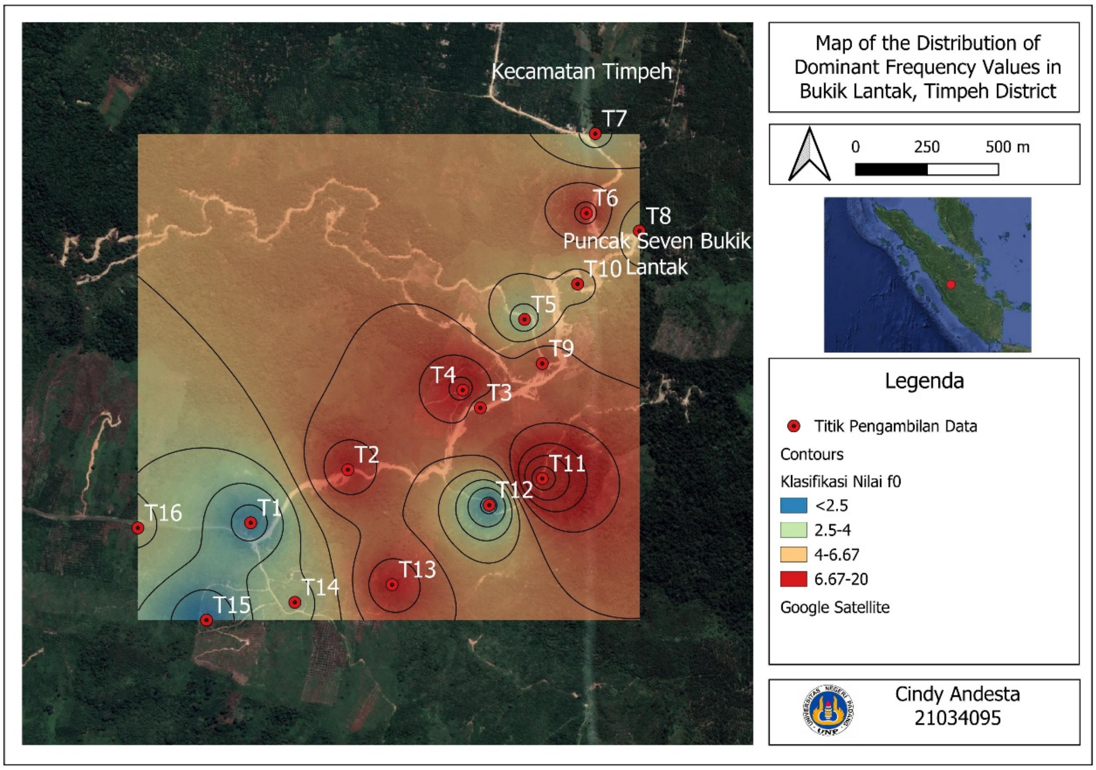

Figure 3. Map of the Distribution of Dominant Frequency Values in Bukik Lantak, Timpeh Subdistrict

Based on Figure 2, the distribution map of the dominant frequency values in the study area is dominated by red, which indicates high f0 values ranging from 6.67 Hz – 9.55 Hz, green and yellow colors represent moderate frequency values ranging from 2.5 Hz – 6.25 Hz, and blue colors indicate low dominant frequency values with a range of 0.1 Hz – 0.7 Hz. Areas with low dominant frequency values have thick sediment layers, and vice versa.

The dominant frequency value of an area is very important to know because this dominant frequency value is usually considered to be the natural value of the soil in that area. The dominant frequency value is related to the thickness of the sediment layer. If a soil has a thick sediment layer, as indicated by a low f0 value, it is assumed that the layer is soft and therefore prone to earthquakes, and vice versa.

3.2 Amplification Factor

The amplification factor measures the degree to which a medium amplifies waves as they travel through it. So, when seismic waves travel through a softer medium than the one they first encountered, the effect is known as amplification. A larger disparity causes the waves to be amplified to a larger extent. [16]. Table 3 shows the amplification classification based on the amplification value at Bukik Lantak, Timpeh Subdistrict, according to soil amplification classification [17].

Table 3. Classification of Amplification Factor Values in Bukik Lantak, Timpeh Subdistrict

Research Focus	**Amplification Factor Value**	**Zone**	**Classification**
TP1, TP2, TP4, TP6, TP8, TP9, TP11, TP12, TP14, TP15	1.11-2.68	1	Low
TP3, TP5, TP7, TP10, TP13, TP16	3.01-4.12	2	Medium

Based on measurement data collected at 16 measurement points, the amplification value in Bukik Lantak, Timpeh Subdistrict, ranged from 1.11 to 4.12. When viewed from Table 3, the Bukik Lantak area falls into the low to moderate amplification category. The distribution of amplification values in the Bukik Lantak area can be seen in Figure 4.

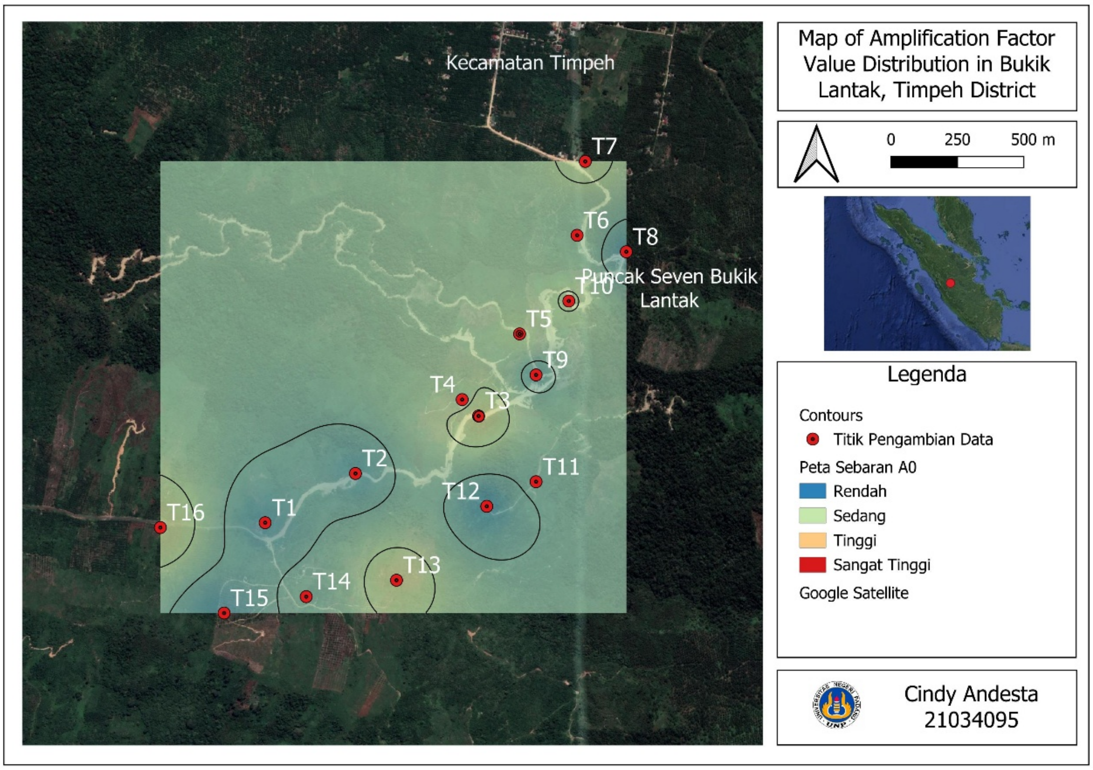

Figure 4. Map of Amplification Factor Value Distribution in Bukik Lantak, Timpeh Subdistrict

Based on Figure 4, areas with low amplification values have values of 1.11–2.68, indicated by blue colors scattered across the Puku formation at research points TP1, TP2, TP4, TP6, TP8, TP9, TP11, TP12, TP14, and TP15. Areas with low amplification values indicate the presence of hard soil layers or shallow bedrock. Meanwhile, areas with moderate amplification factors have values ranging from 3.01 to 4.12, distributed across the Puku Formation at the research sites TP3, TP5, TP7, TP10, TP13, and TP16. Areas with moderate amplification values indicate the presence of moderate to soft soil layers that can amplify seismic waves at a moderate level.

3.3 Shear Wave Velocity (Vs)

Bedrock shear wave velocities (Vs) in the Bukik Lantak area of the Timpeh Subdistrict vary between 120 and 1800 m/s. The bedrock's shear wave velocity values reveal the rock type present there. Referring to the National Standards Agency [18] classification, the shear wave velocity values at Bukik Lantak can be classified as shown in Table 4 below:

Table 4. Classification of Shear Wave Velocity (Vs) Values in Bukik Lantak, Timpeh Subdistrict

Research Focus	Layer	Classification	Value
TP1, TP3, TP5, TP6, TP7, TP8, TP10, TP12, TP14, TP15, TP16	1	Soft Soil	120 - 170 m/s
TP2, TP9, TP11, TP13		Medium Soil	200 - 300 m/s
TP4		Rocks	800 m/s
TP3, TP7, TP12, TP15, TP16	2	Soft Soil	161 - 170 m/s
TP1, TP5, TP6, TP8, TP10, TP14		Medium Soil	200 - 263 m/s
TP4		Rocks	1000 m/s
TP1, TP3, TP12, TP15, TP16	3	Medium Soil	250 - 330 m/s
TP2, TP5, TP6, TP7, TP8, TP9, TP10, TP13, TP14		Solid Soil	350 - 600 m/s
TP4, TP11		Rocks	750 - 1300 m/s
TP1, TP2, TP3, TP5, TP6, TP7, TP8, TP9, TP10, TP12, TP14, TP15, TP16	4	Solid Soil	350 - 700 m/s
TP11, TP13		Rocks	850 - 900 m/s
TP4		Hard Rocks	1800 m/s

Based on the results of the data analysis in Table 4. From 16 measurement points, each with 4 layers and a total of 65 Vs data, it was found that layer one (surface) had values of Vs <175 m/s at almost all points at research point TP1, TP3, TP5, TP6, TP7, TP8, TP10, TP12, TP14, TP15, and TP16, indicating that the top layer is dominated by soft soil, which is prone to landslides when saturated with water and subjected to strong shaking. Layers 2 and 3 have Vs values ranging from 200 m/s - 700 m/s, indicating medium to dense soil, which is also prone to landslides when saturated with water and subjected to strong shaking. Layer 4 is dominated by rock and hard rock with Vs values ranging from 750 m/s - 1800 m/s.

3.4 Seismic Vulnerability Index

The seismic vulnerability index indicates the ability of surface layer of soil to resist deformation. Earthquake Vulnerability Index value indicates soil structure stability., where the higher the seismic vulnerability index value, the lower the stability of the soil structure. The seismic vulnerability index value is influenced by amplification factors and dominant frequencies. The seismic vulnerability index values in Bukik Lantak, Timpeh Subdistrict, are divided into three zones: low, moderate, and high, as shown in Table 5.

Table 5. Classification of Seismic Vulnerability Index Values in Bukik Lantak, Timpeh Subdistrict

Research Focus	Value Kg	Zone	Classification
TP2, TP4, TP6, TP8, TP9, TP10, TP11, TP12, TP13, TP14	0.3052 - 2.44802	1	Low
TP1, TP3, TP5, TP7, TP16	3.00431 - 4.6826	2	Medium
TP15	15.376	3	High

Table 5 shows that a seismic vulnerability index value for Bukik Lantak can be anywhere from 0.3052 to 15.376. Locations with these values range from very vulnerable to very vulnerable to earthquakes. Figure 4 below displays a map depicting the distribution of values for the seismic vulnerability index:

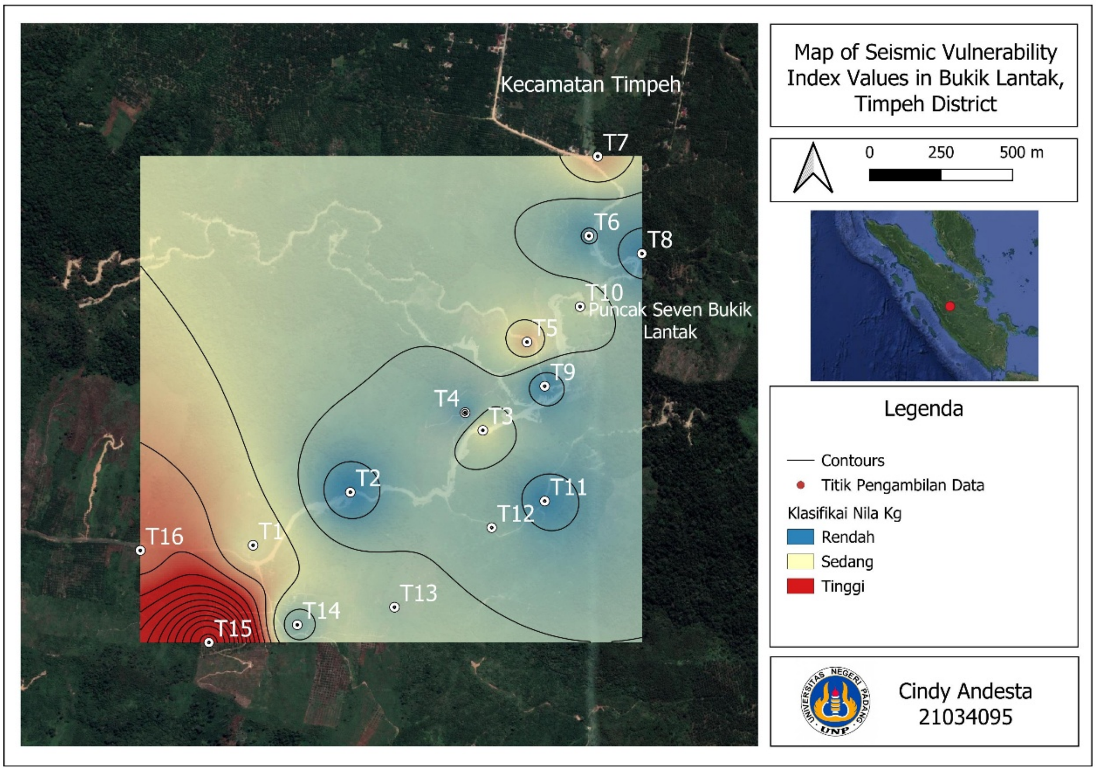

Figure 5. Map of Seismic Vulnerability Index Values in Bukik Lantak, Timpeh Subdistrict

Based on the earthquake vulnerability index distribution map in Figure 4, it can be seen that the study area, based on the earthquake vulnerability index classification [18] in Bukik Lantak, is dominated by a low earthquake vulnerability index, with values ranging from 0.3052 to 2.44802, marked in blue. This means that the study area has relatively thin sediment layers, indicating a low level of vulnerability. Moderate earthquake vulnerability index values, ranging from 3.00431 to

4.6826, marked in yellow, indicate that the soil layers in the zone begin to show amplification responses to earthquake shocks. Meanwhile, the high earthquake vulnerability index value is 15.376, marked in red, indicating the thickness of the sediment layer in the study area. The high earthquake vulnerability index value indicates that the area has a higher potential for hazards and greater building damage during an earthquake.

The seismic vulnerability index can indicate the vulnerability of an area affected by earthquakes or rock layer movements. The higher the seismic vulnerability index of an area, indicated by the color red, the more vulnerable that area is to the effects of tremors. Based on the data obtained, areas vulnerable to the effects of seismic activity or rock movement are referred to as weak zones. The area with the highest earthquake vulnerability is located at the research site TP15, with a value of 15,376. If ground movement occurs in Bukik Lantak and its surroundings, the area most likely to experience landslides are those located at research points TP1, TP3, TP5, TP7, TP15, and TP16. This is also supported by the presence of soft soil layers in the first to second layers.

4. Conclusion

Based on the results of the study in Bukik Lantak, Timpeh Subdistrict, the microtremor parameters in Bukik Lantak show a dominant frequency of 0.1–9.55 Hz, amplification factor of 1.11–4.12, shear wave velocity (Vs) of 120–1,800 m/s, and seismic vulnerability index of 0.3052–15.376. Zones with moderate to high vulnerability are mainly found in hilly and slope areas, and these results are consistent with the landslide event on January 24, 2024, in Bukik Lantak. Landslide-prone areas are characterized by a combination of low dominant frequency, low Vs, high amplification factor, and high seismic vulnerability index. The research points that meet these criteria are TP1, TP3, TP5, TP7, TP15, and TP16. These findings have important implications for disaster mitigation, risk management, and infrastructure planning in Timpeh Subdistrict.

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