

**Seismic Vulnerability Index Analysis Using the HVSR (Horizontal to Vertical Spectral Ratio) Method in Nagari Malampah, Tigo Nagari District, Pasaman Regency**  
Satifa Rahmania<sup>1</sup>, Akmam<sup>1\*</sup>, Hamdi<sup>1</sup>, Zulhendra<sup>1</sup>

<sup>1</sup> Department of Physics, Universitas Negeri Padang, Jl. Prof. Dr. Hamka Air Tawar Padang 25131, Indonesia  
Corresponding author. Email: [akmam\\_db@fmipa.unp.ac.id](mailto:akmam_db@fmipa.unp.ac.id)

**ABSTRACT**

*Pasaman Regency, particularly Nagari Malampah in Tigo Nagari District, is one of the areas prone to seismic activity. This region lies along the active Sumatra Fault Zone and has complex topographical conditions, including mountainous areas, lowlands, and river flows. The earthquake with a magnitude of 6.2 SR that occurred on February 25, 2022, in West Pasaman had a significant impact on Nagari Malampah, causing infrastructure damage and landslides. The lack of public awareness regarding disaster mitigation has further worsened the resulting impacts. This study aims to determine the seismic vulnerability index in Nagari Malampah. The research was conducted in Jorong Siparayo, Nagari Malampah, using a quantitative approach through data collection with microtremor measurements at 16 points. The microtremor signal data were analyzed using the HVSR method with the EasyHVSR software to obtain the dominant frequency, amplification factor, and seismic vulnerability index. Data interpretation was supported by the values of dominant frequency, amplification factor, and seismic vulnerability index obtained at each measurement point. The study carried out in Nagari Malampah, using the HVSR method, resulted in dominant frequency values ranging from 1.45 to 11.45 Hz, amplification factor values ranging from 2.34 to 6.21, and seismic vulnerability index values ranging from 0.60 to 9.33. Furthermore, based on the distribution map of the seismic vulnerability index in Nagari Malampah, Tigo Nagari District, Pasaman Regency, the area has a range of low to high seismic vulnerability levels.*

**Keywords :** Seismic Vulnerability Index, Microtremor, HVSR, Nagari Malampah



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**I. INTRODUCTION**

An earthquake is a sudden shaking or tremor caused by the release of accumulated energy. Earthquakes occur due to tectonic plate movements, active fault displacements, and volcanic activity [1]. A mainshock is often followed by a series of aftershocks with smaller magnitudes centered around the affected area. The uncertainty in predicting the time and location of earthquakes makes this phenomenon difficult to anticipate and poses a high risk to both public safety and infrastructure [2]. One of the regions that has experienced a significant magnitude earthquake is Pasaman Regency.

Pasaman Regency is located in the northern part of West Sumatra Province and consists of 12 districts, 37 nagari, and 225 jorong [3]. One of the nagari significantly affected by seismic activity is Nagari Malampah, which is located in Tigo Nagari District. This nagari covers an area of 137.97 km<sup>2</sup> and has a population of 10,628 people. Geographically, the area is situated near the active Sumatra Fault Zone and features diverse topography, including mountains, lowlands, and river flows that overall support the local economic activities. However, these conditions also make the area vulnerable to natural disasters such as landslides, earthquakes, and soil movement, especially during the rainy season or in the event of seismic activity [4].

The earthquake that occurred on February 25, 2022, with a magnitude of 6.2 SR and a depth of 10 km in West Pasaman caused serious impacts, particularly in Nagari Malampah. The earthquake damaged 24 houses, 2 elementary schools, 2 bridges, 2 places of worship, and one auxiliary health center. In addition to structural damage, the earthquake also triggered landslides in the area [5]. This situation highlights the importance of proper mitigation measures to reduce the impact of future disasters.

One of the mitigation methods that can be applied is microtremor analysis using the Horizontal to Vertical Spectral Ratio (HVSr) method. Microtremor data processing through the HVSr method yields parameters such as the dominant frequency ( $f_0$ ) and amplification factor ( $A_0$ ), which can then be used to calculate the seismic vulnerability index (Kg) and sediment thickness. The resulting values will be analyzed to identify areas that are potentially prone to landslides [6]. The equation used in HVSr calculations is as follows [7]:

$$HVSr = \frac{\sqrt{[(S_{Utara-Selatan})^2 + (S_{Barat-Timur})^2]}}{S_{Vertikal}} \quad (1)$$

The dominant frequency ( $f_0$ ) is the frequency at which ground vibrations are most amplified at a specific location during an earthquake. Soils composed of fine materials tend to have a low dominant frequency ( $f_0$ ) and are more susceptible to shaking, especially when saturated with water. This condition can lead to landslides in the soil layer. The HVSr method is used to determine the dominant frequency and estimate the potential for landslides. Mathematically, the dominant frequency ( $f_0$ ) can be expressed as follows [8]:

$$f_0 = \frac{V_s}{4H} \quad (2)$$

where:

( $f_0$ ) is the dominant frequency

$V_s$  is the average shear wave velocity

H is the thickness of the weathered layer.

The dominant frequency value ( $f_0$ ) can reflect the geological conditions of an area. High values indicate hard bedrock and thin sediment layers, while low values (below 2.5 Hz) signify thick sediment and soft rock. Areas with low dominant frequency ( $f_0$ ) are more vulnerable to earthquake shaking. Soil can be classified based on the dominant frequency value ( $f_0$ ) according to Kanai [9], as shown in Table 1.

**Table 1.** Classification of Dominant Frequency Values ( $f_0$ )

Type	Category	Dominant Frequency (Hz)	Kanai Classification	Description
IV	I	6.67 – 20	Tertiary or older formations are composed of hard sandy gravel and various other rock types	Sediment thickness is very thin at the surface and is dominated by hard rock
III	II	4.0 – 6.67	Alluvial rocks, with a depth of 5 meters, consist of sandy gravel, sandy hard clay, loam, and others	Surface sediment thickness ranges from 5 to 10 meters
II	III	2.5 – 4.0	Alluvial deposits with a thickness of more than 5 meters, consisting of sandy gravel, sandy hard clay, loam, and others	The surface sediment thickness falls into the thick category, approximately 10 to 30 meters
I	IV	< 2.5	Alluvial deposits formed from deltaic sedimentation, topsoil, mud, and other materials,	The surface sediment thickness is very thick

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with a depth of  $\geq 30$   
meters.

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The amplification factor ( $A_0$ ) is a phenomenon of increased seismic wave amplitude caused by differences in impedance between soil layers. Soft soil with low impedance and wave velocity tends to amplify the amplitude and extend the duration of shaking. Mathematically, the amplification factor ( $A_0$ ) can be expressed as follows [10]:

$$A_0 = \frac{A_{S(H)}}{A_{B(V)}} \quad (3)$$

Where:

( $A_0$ ) is the amplification factor

$A_{S(H)}$  is the horizontal component spectrum (surface)

$A_{B(V)}$  is the vertical component spectrum (bedrock)

Deformation of rocks due to weathering, folding, and faulting alters the physical properties of the rocks, such as elasticity modulus and density, thereby affecting wave velocity and increasing amplification. The amplification factor ( $A_0$ ) values can be classified into four zones: low, medium, high, and very high [11].

**Table 2.** Classification of Amplification Factor Values ( $A_0$ )

Zone	Classification	Amplification Factor Value
1	Low	$A < 3$
2	Medium	$3 \leq A < 6$
3	High	$6 \leq A < 9$
4	Very High	$A \geq 9$

The seismic vulnerability index can indicate the susceptibility of soil to deformation caused by earthquakes. High values signify a potential for severe damage, especially in areas with low dominant frequency ( $f_0$ ) and thick sediment layers that amplify shaking. The seismic vulnerability index is determined by the dominant frequency ( $f_0$ ), amplification factor ( $A_0$ ), and sediment thickness. High values indicate thick sediments, while low values indicate thin sediments. The seismic vulnerability index can be formulated as follows [12]:

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

where:

( $A_0$ ) is the amplification factor value

( $f_0$ ) is the dominant frequency

The seismic vulnerability index indicates the susceptibility of an area to deformation measured at a specific point. According to Refrizon (2013), the seismic vulnerability index ( $Kg$ ) is classified as follows [13]:

**Table 3.** Classification of Seismic Vulnerability Index Values ( $Kg$ )

Zone	Classification	Seismic Vulnerability Index
1	Low	$Kg < 3$
2	Medium	$3 < Kg < 6$
3	High	$Kg > 6$

Based on the issues, research on the seismic vulnerability index is needed in Jorong Siparayo, Nagari Malampah, Tigo Nagari District, Pasaman Regency. This study aims to determine the seismic vulnerability index in hazard zones affected by ground movement due to shaking or layer displacement, thereby assisting in disaster mitigation efforts and safer regional planning.

## II. METHOD

The research was conducted in Jorong Siparayo, Nagari Malampah, Tigo Nagari District, using microtremor data measurements at 16 measurement points. Data collection was carried out for 25 to 55 minutes with a spacing of approximately 250 to 400 meters between points. The data obtained are direct measurements from the study area. These data will be processed using the HVSR method to obtain values of dominant frequency ( $f_0$ ), amplification factor ( $A_0$ ), and the seismic vulnerability index ( $K_g$ ).

This study utilized instruments and research materials consisting of hardware and software. The hardware used includes Sysmatrack-M.AE, Seismometer Type S3S, connecting cables between the Sysmatrack-M.AE and Seismometer Type S3S, a compass, GPS, and a laptop. The software used comprises EasyHVSR, Google Earth, Microsoft Excel, and QGIS. The microtremor data acquisition technique refers to the standard operational procedures for microtremor measurements [10]. Subsequently, the obtained microtremor data were processed using the HVSR method, with data processing carried out using the EasyHVSR software.

The microtremor data obtained were processed using EasyHVSR software to determine the dominant frequency ( $f_0$ ) and amplification factor ( $A_0$ ) at each measurement point. The data consist of three components: two horizontal (North–South and East–West) and one vertical. The initial stage involved windowing to select noise-free data segments of 20–30 seconds, where noise was identified by sudden and unstable increases in amplitude. The clean data were then subjected to Hanning windowing to reduce frequency distortion during the Fourier transform, resulting in a smoother and more accurate HVSR spectrum. Subsequently, the data were transformed from the time domain to the frequency domain through the Fourier transform. Smoothing was performed using the Konno-Ohmachi method to stabilize the H/V spectrum. The horizontal components were combined using the root mean square average, followed by calculating the ratio between the horizontal and vertical components (H/V). The obtained dominant frequency and amplification factor values were then used as the basis to calculate the seismic vulnerability index ( $K_g$ ).

## III. RESULTS AND DISCUSSION

### A. RESULTS

This study was conducted in Nagari Malampah, Tigo Nagari District, Pasaman Regency. Microtremor data were collected using a Sysmatrack MAE seismograph set and processed with EasyHVSR software. The data obtained through the HVSR method produced values of dominant frequency ( $f_0$ ), amplification factor ( $A_0$ ), and seismic vulnerability index ( $K_g$ ) in Nagari Malampah, Tigo Nagari District, Pasaman Regency.

**Table 4.** Results of Dominant Frequency ( $f_0$ ), Amplification Factor ( $A_0$ ), and Seismic Vulnerability Index

Measurement Points	Latitude	Longitude	Dominant Frequency (Hz)	Amplification Factor	Seismic Vulnerability Index
1	0.0668	100.0642	1.45	3.68	9.33
2	0.0698	100.06278	11.45	2.97	0.77
3	0.0725	100.06139	3.25	4.45	6.09
4	0.075	100.06028	2.35	3.79	6.11
5	0.0764	100.05972	3.25	3.44	3.64
6	0.0784	100.0592	9.85	4.64	2.18
7	0.07639	100.05806	2.95	2.37	1.90
8	0.07444	100.05583	3.4	3.49	3.58
9	0.0717	100.0575	2.5	2.45	2.40

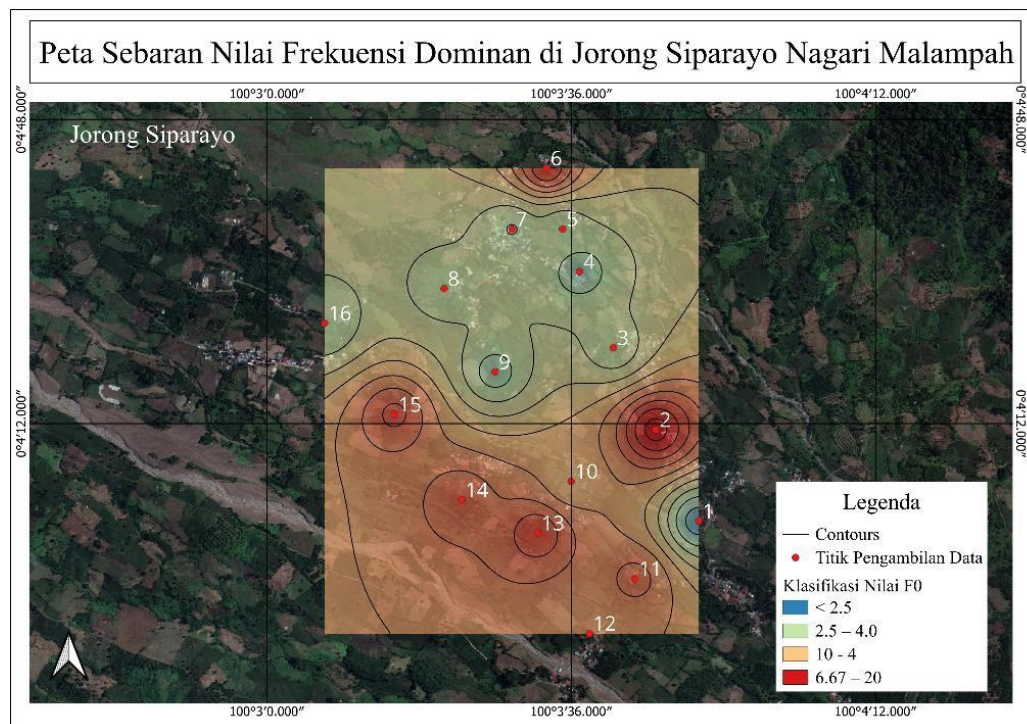
10	0.0681	100.06	6.25	3.22	1.65
11	0.0649	100.0621	8.35	2.34	0.65
12	0.0631	100.0606	7	3.97	2.25
13	0.0664	100.0589	9.85	6.21	3.91
14	0.0675	100.0564	8.8	5.88	3.92
15	0.0703	100.0542	9.25	2.36	0.60
16	0.0733	100.0519	3.1	3.16	3.22

**B. Discussion**

1. Dominant Frequency

The dominant frequency obtained from microtremor waves can reflect the geological characteristics of the study area. Therefore, the magnitude of the dominant frequency value is influenced by the subsurface structural conditions in that area. A high dominant frequency value indicates a region composed of hard rock and thin sediment layers. Conversely, a dominant frequency value below 2.5 Hz indicates an area consisting of soft rock and thick sediment layers [14].

The study locations with low dominant frequency values range from 1.45 to 3.4 Hz, indicating areas with thick sediment layers and soft soil structures. Meanwhile, high dominant frequency values ranging from 6.25 to 11.45 Hz represent areas with thin sediment layers and hard soil. This is caused by the depth of the boundary between the sediment layer and the hard bedrock beneath the surface. The distribution of dominant frequency values reflecting these conditions can be seen in Figure 1.



**Figure 1.** Distribution Map of Dominant Frequency Values

Based on Figure 1, the Distribution Map of Dominant Frequency Values obtained from microtremor measurements in Table 4, it can be seen that Nagari Malampah has high frequency values at points T2, T6, T10, T11, T12, T13, T14, and T15. The dominant frequency can be classified according to the values by [9] into types I and II, which consist of tertiary rocks, where a high dominant frequency ( $f_0$ ) indicates thin sediment thickness and hard soil, such as hard sandy gravel and hard sandy clay rocks with a depth of less than 5 meters.

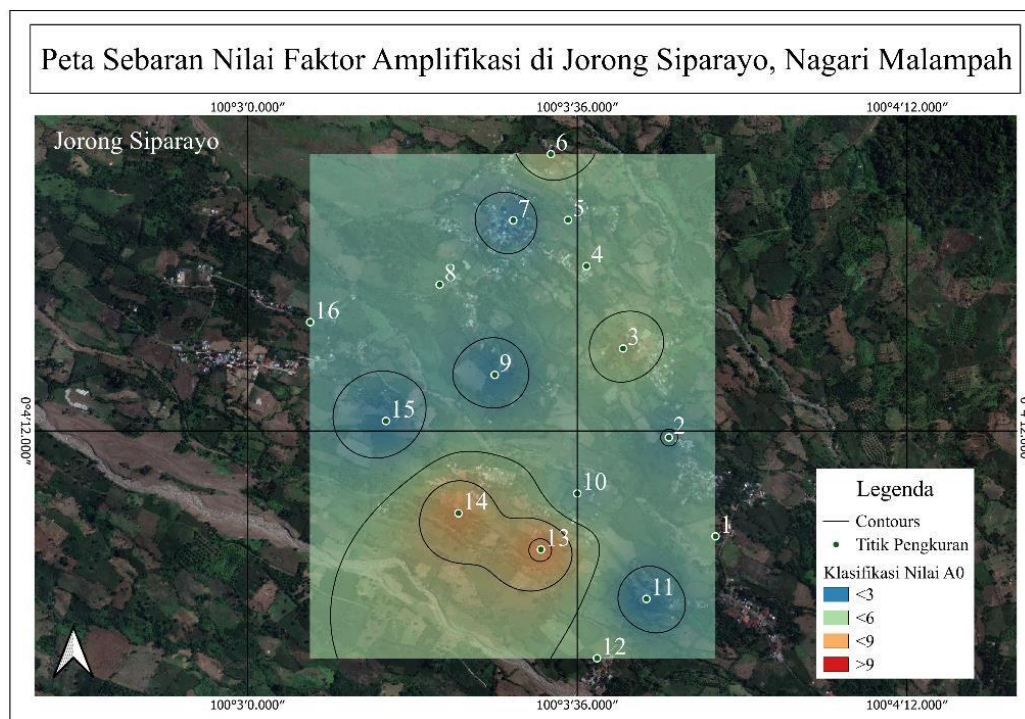
Low dominant frequency ( $f_0$ ) values found at points T1, T3, T4, T5, T7, T8, T9, and T16 are located in the Young Quaternary Alluvial Formation (Qat1), which was formed through river sedimentation processes and generally consists of coarse gravel, sand, silt, and clay. This corresponds to the classification by [9] as soil types III and IV, indicating thick and soft sediments. The constituent rocks may include sandstone and alluvial deposits with a depth of  $\geq 30$  meters. Areas with low dominant frequency tend to be more susceptible to earthquake shaking.

These findings are supported by several previous studies that also show the relationship between low and high dominant frequency values with sediment thickness and seismic vulnerability. In the studies by Dian [15], Mentari [11], and Nurwidyanto [16], it was revealed that areas with high dominant frequency values tend to have thin sediment layers and relatively dense subsurface structures, which influence the level of seismic vulnerability in a region. Conversely, thick soft sediment and alluvial layers have low dominant frequency values and a high potential for earthquake amplification. These three studies reinforce that low dominant frequency values correspond to higher vulnerability levels to seismic shaking.

## 2. Amplification factor

The amplification factor value reflects the level of vulnerability of an area to seismic activity, where areas with soft sediment surfaces tend to have higher amplification factor values compared to areas composed of hard sediment. This is due to the high contrast between soft sediment and bedrock, which causes seismic waves to be more easily amplified in such areas. The amplification value is strongly influenced by soil characteristics, such as soil density, sediment layer thickness, and the presence of bedrock beneath [17].

Based on Table 4, the amplification factor results at each measurement point show that the highest value is at point 13 with a value of 6.21. The amplification factor values classified as medium range from 3.68 to 5.88, while the low amplification factor values range from 2.34 to 2.97. The distribution of the amplification factor values obtained can be seen in Figure 2 below.



**Figure 2.** Distribution Map of Amplification Factor Values

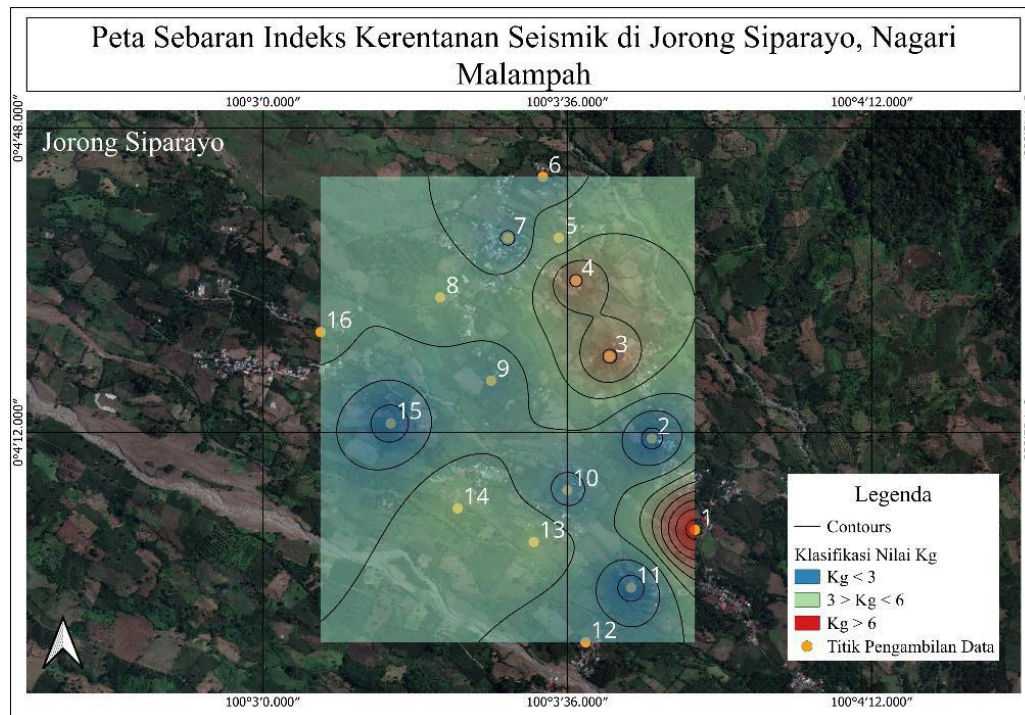
Low amplification factor values are found at points T2, T7, T9, T11, and T15. Low amplification values may indicate soil conditions that are relatively stiff or dense, making them more stable against earthquake amplification. This information is important as a basis for earthquake risk assessment, disaster mitigation, and regional spatial planning.

These findings are supported by the study of Arintalofa [18], which showed that amplification values are closely related to subsurface geological characteristics based on HVSR analysis. Furthermore, research by Dian [15] and Mentari [11] also demonstrated that zones with high amplification values are generally located in areas with soft sediments, which have the potential to increase the seismic vulnerability of the region.

### 3. Seismic Vulnerability Index

The seismic vulnerability index is a parameter used to assess the level of vulnerability of an area to the impacts of earthquake shaking, landslides, and volcanic eruptions, calculated based on microtremor measurements. The seismic vulnerability index is obtained from the ratio between the amplification factor and the dominant frequency value at each measurement point, reflecting the local seismic response to earthquake waves. Higher seismic vulnerability index values indicate greater amplification potential, making the area more susceptible to damage during an earthquake [19].

Based on data from 16 measurement points in Nagari Malampah, it is known that the majority of the area has seismic vulnerability levels classified as high, medium, and low. The distribution of seismic vulnerability index values in the high category ranges from 6.09 to 9.33. The seismic vulnerability index values in the medium category range from 3.22 to 3.92. Meanwhile, the values in the low category range from 0.60 to 2.40, indicating locations that are less vulnerable to earthquake shaking amplification. The spatial distribution pattern of the seismic vulnerability index values can be seen in Figure 3 below.



**Figure 3.** Distribution Map of Seismic Vulnerability Index

Based on the seismic vulnerability index ( $K_g$ ) values, the area can be classified into high, medium, and low categories following the amplification factor values. Zone 3 shows the highest vulnerability level, located at points T1, T3, and T4. Zone 1 is dominated by points with low vulnerability at T2, T6, T7, T9, T10, T11, T12, and T15, reflecting soil conditions that are relatively stable against earthquake shaking. Meanwhile, Zone 2, located at T5, T8, T13, T14, and T16, represents a more balanced distribution between medium and low vulnerability.

These findings are consistent with the study by Mentari [11], which showed that the distribution of seismic vulnerability index values is strongly influenced by variations in subsurface geological conditions. Dian's research [15] also found that areas with high amplification values have greater vulnerability levels, especially in landslide-prone regions. Additionally, the study by Arintalofa [18] emphasized the importance of analyzing subsurface characteristics using the HVSR method to understand seismic distribution, which in turn affects the classification of vulnerability zones in an area.

This requires greater attention in spatial planning and the development of earthquake-resistant infrastructure. As part of disaster mitigation efforts for earthquakes, landslides, and ground movement, the seismic vulnerability index ( $K_g$ ) map can be utilized to illustrate the level of soil vulnerability in an area. The map produced by this study serves as an important basis for spatial planning and infrastructure development in Jorong Siparayo, Nagari Malampah. This information is used to direct development toward safer zones, reinforce building structures in vulnerable areas, and design sustainable disaster management strategies according to the level of potential damage in each zone.

#### IV. CONCLUSION

Based on the analysis results using the HVSr (Horizontal to Vertical Spectral Ratio) method, the dominant frequency ranges from 1.45 to 11.45 Hz, the amplification factor values range from 2.34 to 6.21, and the seismic vulnerability index values range from 0.60 to 9.33. Furthermore, based on the distribution map of the seismic vulnerability index in Nagari Malampah, Tigo Nagari District, Pasaman Regency, the vulnerability index varies from low to high. These analysis results are important for understanding the vulnerability level of the area to earthquakes and serve as a basis for planning seismic disaster mitigation in the study area.

#### ACKNOWLEDGMENT

Thank you to the Department of Physics, Faculty of Mathematics and Natural Sciences, Universitas Negeri Padang for their assistance during the writing process of this article. We appreciate the support and help provided to the author.

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