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Seismic Vulnerability Microzonation Using Hvsr Method in Kalisalak Hamlet, Garunglor Village, Sukoharjo Sub-District, Wonosobo District

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Abstract

Kalisalak Hamlet in Sukoharjo District is faced with the risk of landslides that can affect the structure of residents' houses. This study aims to identify potential landslide zones based on the parameters of Dominant Frequency (f_0), Amplification Factor (A_0), and Seismic Vulnerability (K_g)to determine areas that are potentially vulnerable to landslides. Microseismic measurements were carried out at 25 measurement points in the landslide zone. Measurements used a 3-component digital portable seismograph (North-South, West-East, and Vertical). Microseismic data were processed using Geopsy software with the HVSR (Horizontal-to-Vertical Spectral Ratio) method to obtain an H/V curve that provides Dominant Frequency (f_0) and Amplification Factor (A_0) values. The results showed that Kalisalak Village has a dominant frequency value between 3 Hz to 12.5 Hz and an amplification factor value between 1.4 to 6.8. This variation indicates that some areas are more susceptible to seismic vibration amplification. Based on the Dominant Frequency (f_0) value and Amplification Factor (A_0), a Seismic Vulnerability (K_g) microzonation map was created for Kalisalak hamlet with a value range of 0.2 to 7 with a high vulnerability value located in the landslide area south of the village. This map is important for disaster mitigation planning in Kalisalak hamlet.

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INTRODUCTION

Wonosobo is a mountainous area with an altitude of 250-2,250 meters above sea level and varying land slopes, making it vulnerable to natural disasters such as landslides. (Dinas Lingkungan Hidup, 2021; Highland, 2008). Wonosobo Regency belongs to the physiography of the Northern South Serayu Mountains and is dominated by Quaternary volcanic deposits. (Van Bemmelen, 1949).The area has a tropical climate with high rainfall that affects soil and slope conditions, increasing the potential for landslides. (Lavigne et al., 2008; Pradana, 2015; Salam R. A et al., 2019). Several sub-districts in Wonosobo, including Dukuh Kalisalak in Sukoharjo sub-district, face a high risk of landslides that damaged several houses. The houses had cracks in the walls, and even the supporting poles that were supposed to be perpendicular appeared tilted, as shown in Figure 1.

Figure 1. The impact of landslides that occurred in Kalisalak Hamlet
(Field Documentation, 2024)

This situation signals the urgent need for preventive measures and structural improvements in Kalisalak hamlet to reduce potential hazards and protect the safety and assets of the local community. The use of microseismic method by detecting seismic waves from natural activities can help in mapping the landslide risk in this area. This research aims to identify potential ground motion zones based on the parameters of f_0, A_0, and K_g in Dukuh Kalisalak. The results of the research are expected to be the basis for disaster mitigation of Dukuh Kalisalak which is located in a landslide-prone area.

METHOD

The HVSR method was originally introduced by (Nogoshi & Igarashi, 1971) and since then has continued to experience development and improvement through the contributions of various researchers, especially by (Nakamura, 1989, 2000, 2008). By utilizing the spectral ratio between the horizontal and vertical components of seismic waves, this method can identify the dominant frequency reflected by the interaction between waves and local soil structures. HVSR analysis uses the following formula.

$$R(f) = \frac{\sqrt{H_{EW^2}(f) + H_{NS^2}(f)}}{V_{UD}(f)} \quad (1)$$

with $R(f)$ is the HVSR ratio spectrum, $H_{EW}(f)$ is the west-east horizontal component spectrum, $H_{NS}(f)$ is the spectrum of the north-south horizontal component, and $V_{UD}(f)$ is the vertical component spectrum.

Seismic susceptibility is directly proportional to seismic amplification (Nakamura, 2008). Seismic vulnerability analysis uses the following formula.

$$K_g = \frac{A_0^2}{f_0} \tag{2}$$

with K_g is seismic susceptibility, A_0 is the dominant amplification, and f_0 is the dominant Frequency. The Horizontal-to-Vertical Spectral Ratio (HVSR) method is used to determine seismic vulnerability by analyzing the spectral ratio between the horizontal and vertical components of seismic waves. The characteristic peaks or indentations in the HVSR curve are used to identify seismic susceptibility (Rahma *et al.*, 2022). The following is the survey design and measurement points of the research location in Figure 2.

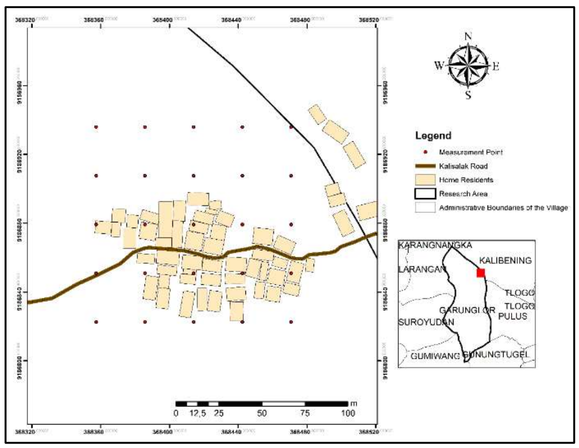

Figure 2. Reseacrh Site Survey Design

The data used in this study include three-component microtremor recordings measured with a single station as well as secondary data such as geological maps and Google Earth images.

This research was conducted from January 23 to February 7, 2024, data collection techniques by placing the sensor at the measurement point in **Figure 2** with a recording duration of 30 minutes in daylight conditions and minimal noise according to the recommendations of SESAME (2004). The data processing used a number of software and hardware. The following is the software used in the research:

1. Microsoft Office Home & Students 2019, used to display H/V curves and compile research reports.
2. ArcGIS/ArcMap10.8, used to create geological maps, contour maps, and area maps.
3. Google Earth Pro, used to determine data collection points and estimate the condition of the study area.
4. Surfer 21, used to organize the map layout.
5. Geopsy, used to manage microtremor data with HVSR.

The hardware used in the research data collection consists of a set of seismometers that includes:

1. 3-component seismometer sensor (horizontal North-South (NS), East-West (EW), and vertical (V) components), used to record ambient vibrations.
2. Connector cable, serves to connect the sensor, digitizer, and battery.

3. Compass, serves to determine the orientation direction of the sensor and as a water pass sensor.

Figure 3. Microseismic Equipment (MAE Vibralog), 1) 3-Component MAE Sensor, 2) Digital Seismograph (Vibralog), 3) Digitizer to Sensor Connecting Cable

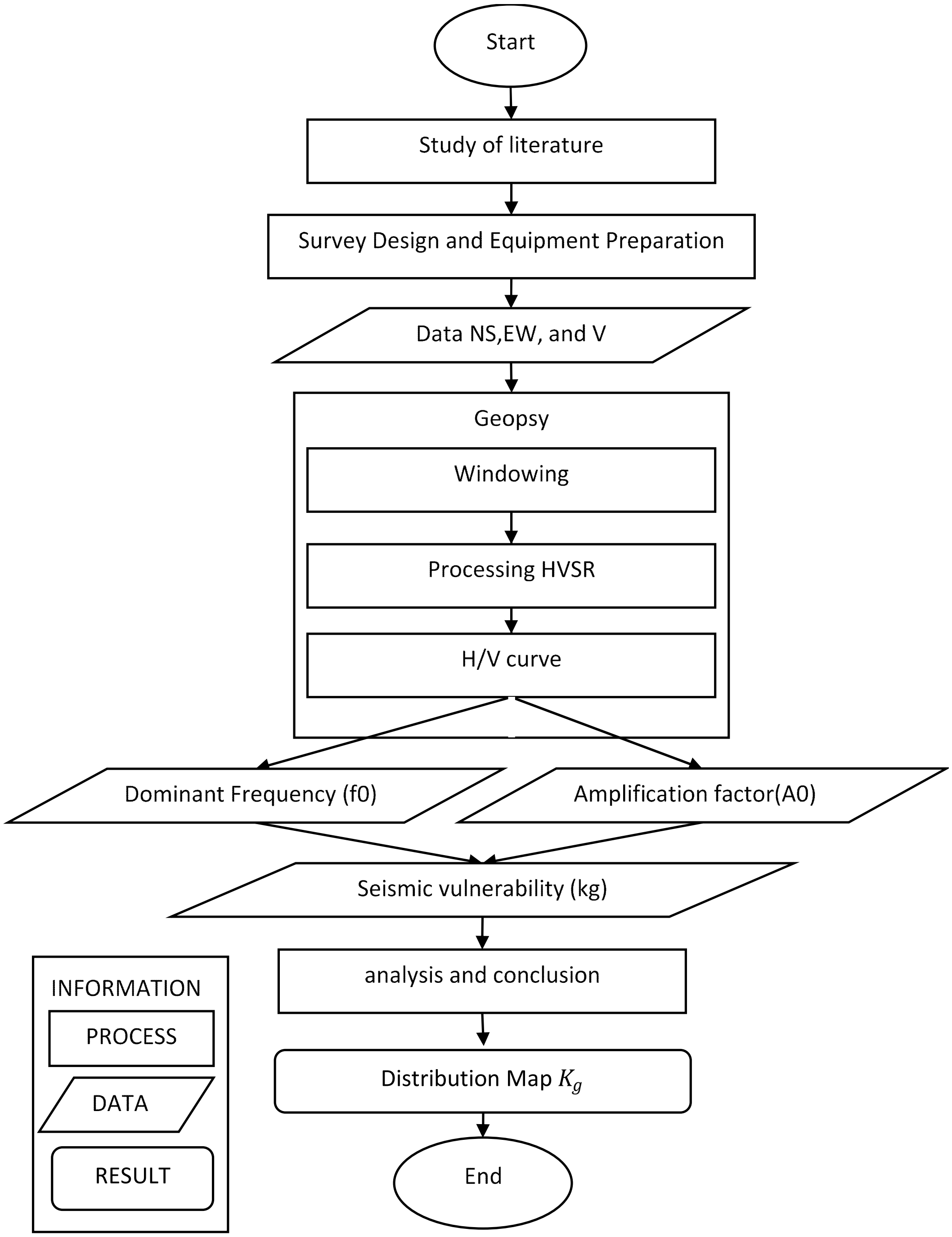

Figure 4. Research Workchart

The research began by conducting a literature review to obtain information on geology and landslides, which was necessary to determine the location and design the research survey. Measurements were carried out in accordance with the research survey design, with a distance of about 10 meters between measurement points, and a total of 25 measurement points taking into account the geological and topographic conditions of the research area. Single station measurements were conducted using tri-directional sensors that measure ground vibration in three directions, namely North-South (NS), East-West (EW), and vertical (V). The measurement duration was adjusted according to the procedure (SESAME, 2004). The three-component microseismic data generated from the measurements were then processed using Geopsy software with the H/V method. The H/V process is carried out to produce H/V curves that provide values of Dominant Frequency and Amplification Factor. (f_0) and Amplification Factor (A_0). Data processing to obtain H/V curves follows the standards described in SESAME 2004.

Data processing involved data format conversion, horizontal-vertical component merging. The mean HVSR value and standard deviation were calculated to determine the reliability of the HVSR curve. Determination of the values of (f_0) and (A_0) is done by finding the highest peak in the HVSR curve. The Dominant Frequency and Amplification Factor were then used to establish seismic susceptibility, which is an indicator of areas susceptible to intense ground motion.

RESULTS AND DISCUSSION

This research was conducted in Kalisalak hamlet, Garunglor village, Sukoharjo sub-district, Wonosobo district, where data were collected from 26 location points. This research aims to provide an overview of seismicity in the area by analyzing the Tapak and Ligung geological formations. Field data was processed using Geopsy software which produced an average HVSR curve and obtained dominant frequency values of (f_0) between 3.3 Hz - 12.8 Hz, which is classified according to Kanai and Tanaka (1961) (Kanai & Tanaka, 1961).

Table 1. Dominant Frequency Value (f_0)

Soil Clasification		**Dominant Frequency (Hz)**	**Location**	**Soil Description**
Tipe	**Jenis**			
I	IV	<2,5		
III	III	2,5 – 4	M11, M23, M24, M25.	The thickness of the sediment surface is categorized as thick, abour 10-30m
IV	II	4 – 10	M1, M2, M3, M4, M5, M7, M10, M12, M13, M14, M15, M16, M17, M18, M19, M21.	Surface sediment thickness falls into the medium category 5-10m
	I	6,667 – 20	M6, M8, M9, M20, M22, M26.	Thin sedimentary surface thickness dominated by hard rock

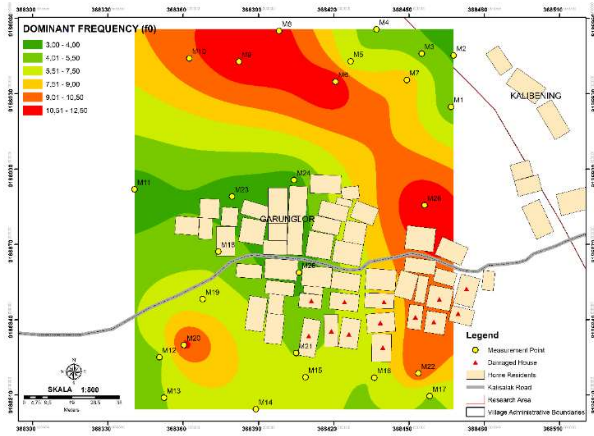

Figure 5. Dominant Frequency Map (f_0)

The dominant frequency distribution shows the seismic heterogeneity of the ground at the measurement site. The low-frequency region is dominated by thick sediments that have the potential to cause multireflection of earthquake waves. Thick sediments are usually weaker than solid rocks such as igneous or metamorphic rocks, which are below them. This weak nature causes the sediment to be unable to withstand tectonic pressure well, making it more easily deformed when an earthquake occurs. Amplification factor analysis (A_0) analysis shows a moderate amplification value in Kalisalak hamlet, indicating the possibility of moderate damage in the event of an earthquake. The Amplification Factor value is related to wave amplification (Ambarsari, 2017).

Table 2. Amplification Factor Values (A_0)

Zone	Clasification	Amplification Factor Value	Location
1	Low	$A < 3$	M1, M11, M15, M18, M19, M20, M21, M22, M23
2	Medium	$3 \leq A < 6$	M2, M3, M4, M5, M6, M7, M9, M10, M12, M13, M14, M17, M24, M25, M26
3	High	$6 \leq A < 9$	M8, M16
4	Very High	$A \geq 9$	

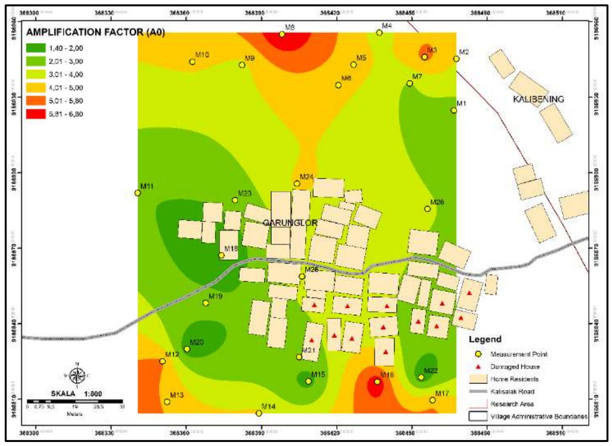

Figure 6. Amplification Factor Map (A_0)

Seismic susceptibility (K_g) is directly proportional to the amplification factor and inversely proportional to the dominant frequency. Values K_g range from 0.17-7.20, with higher areas more vulnerable to earthquake shaking. Visualization of the parameter distribution K_g in Figure 7 shows that most of Kalisalak hamlet has medium vulnerability, while some areas show high vulnerability as evidenced in the field documentation in Figure 8, Figure 9.

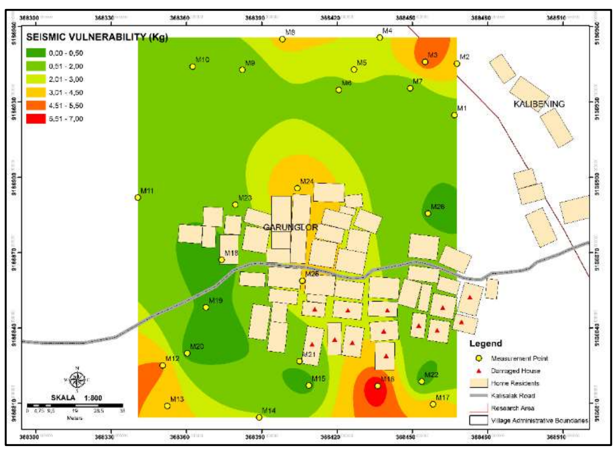

Figure 7. Seismik Vulnerability Microzoning Map (K_g)

Figure 8. M16 Point Documentation   Figure 9. M24 Point Documentation

CONCLUSION

The conclusion of the study found that: Dukuh Kalisalak has dominant frequency values ranging from 3 hz to 12.5 hz, amplification factor values ranging from 1.4 to 6.8. Based on the value of the dominant frequency and amplification factor, a seismic vulnerability microzoning map is produced at Kalisalak Hamlet, Garunglor Village, Sukoharjo District, Wonosobo Regency which has a value ranging from 0.2 to 7. Based on the classification of the three parameters, it is identified that the amplification is quite high, the vulnerability value is medium, and the variation of soil characteristics is quite significant.

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