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Visualization of Microseismic Processing by Coding with GNU Octave

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Abstract

The use of software in the field of geophysics is often limited to the instantaneous use of interfaces without a deep understanding of the computational processes behind them. This leads to limitations in data interpretation and the development of new methods. To address this issue, it is necessary to explicitly visualize the data processing process through programming in order to strengthen computational thinking skills, which are one of the important competencies of the 21st century. This study aims to visualize the microseismic data processing process using programming in GNU Octave software. The method used is a simulation of microseismic data processing based on the HVSR (Horizontal to Vertical Spectral Ratio) approach, with field data collected from the Yogyakarta area. The processing is carried out by building a programming script in GNU Octave, the results of which are then compared with the Geopsy software as a verification tool. The research results indicate that data processing visualization using the HVSR method through GNU Octave can be performed effectively, and the results exhibit high consistency with the output from Geopsy. The dominant frequency on both curves is the same at a frequency of 1.59 Hz. In addition to the dominant frequency, the HVSR curve shape of both software also shows a similar trend pattern in the mid to high frequency range (around 2–10 Hz), where the amplification value decreases gradually. This demonstrates the accuracy of the developed script and proves that this approach can serve as an educational tool for understanding the functioning of geophysical software in a more transparent and in-depth manner. Programming with GNU Octave can be used as an efficient and accurate geophysical analysis tool. This provides opportunities for users, especially in academic environments with limited access to commercial software.

Keywords: *GNU Octave; HVSR; Microseismic; Visualization.*

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1. INTRODUCTION

Geophysics is a branch of science that studies the earth through the approach of physical principles. This science is often used to study various natural phenomena such as earthquakes, volcanic activity, and liquefaction. One of the geophysical methods commonly used in identifying earthquake-prone areas is microseismic. Microseismic is a low-frequency ground vibration that can reflect the subsurface structure. The microseismic method has been used in various previous studies. Riswandi et al (2023), for example, applied it to map earthquake-risk areas through the Probabilistic Seismic Hazard Analysis (PSHA) approach and maximum ground acceleration (PGA) estimation. Meanwhile, Perdhana & Nurcahya (2019) used the microtremor method in their study in Bantul and Klaten Regencies, Central Java. Putra & Saputra (2022) also conducted a study on the level of vulnerability of high-rise buildings in a campus environment. In addition, Prabowo et al. (2020) studied the potential seismic vulnerability in the UST Physics Education Study Program room using the Floor Spectral Ratio (FSR) method, and the results were associated with the classification contained in SNI 2002 concerning earthquake-resistant building planning. These studies prove that microseismic techniques are effective in identifying vulnerability in both buildings and areas to the impact of earthquakes.

This microseismic data is usually processed by previous researchers using certain software, such as Geopsy, to produce important information such as dominant frequencies and amplification values that indicate site effects. For example, research by Haerudin et al (2020) shows that Geopsy is able to identify site characteristics based on microseismic data. However, most Geopsy users tend to only use the graphical interface (GUI) through the menu clicking process without understanding the computational process behind it. This is reflected in the research by Handayani et al (2023) who documented the stages of data processing using Geopsy visually, but did not explain how the software carried out its calculation process. As a result, even though results can be obtained, users do not gain a deep understanding of the physics and computational principles used by the software. When the software is ready, researchers cannot flexibly adjust the analysis parameters or develop new methods that suit the needs of a specific study (Sulistya, 2004). This greatly limits creativity and innovation in research. GNU Octave can be used to create numerical simulations, spectral analysis, inversion methods, machine learning, or advanced geophysical visualizations things that are difficult or impossible to do with just a click in software like Geopsy.

This problem shows the need for a more transparent and educational approach to understanding geophysical data processing. One approach that can be used is through programming or recoding the process carried out by the software. By writing code manually, users can understand the stages of data processing as a whole, from transforming time-domain data to frequency to calculating spectrum ratios. This approach is also in line with the development of computational thinking, namely logistical and algorithmic thinking skills that are important to master in today's digital era (Korucu et al., 2017; Christi & Rajiman, 2023)

As a solution, this study utilizes GNU Octave software to visualize the microseismic data processing process programmatically. GNU Octave is open-source software that has similar capabilities to MATLAB, but can be used for free and is more easily accessible (Purnama et al., 2021). By using GNU Octave, users not only get the processing results, but can also understand how the algorithm works that has been hidden behind the Geopsy interface.

Until now, there has been no research that explicitly visualizes the process of processing microseismic data using GNU Octave, especially with the HVSR (Horizontal to Vertical Spectral Ratio) method approach. The HVSR method itself is a common technique in seismic microzonation studies that compares the spectrum of horizontal and vertical components of ground vibrations to identify sediment layers and subsurface structures (Yuliawati et al., 2009). Therefore, this study aims to visualize the process of processing microseismic data using the HVSR method through programming in GNU Octave. In addition to providing an alternative in translating geophysical data, this approach also encourages the development of computational thinking skills that are crucial in modern geophysical education and research.

2. METHODS

The research method used in this study is microseismic processing simulation using GNU Octave. GNU Octave is a duplication of MATLAB software. GNU Octave was chosen because it is open source software that can be downloaded and used for free by anyone without having to buy a license. In contrast, software such as MATLAB is paid software that requires an official license, which may be an obstacle, especially for educational institutions, independent researchers, or students who have limited budgets. GNU Octave provides various signal processing functions such as Fast Fourier Transform (FFT), filtering, windowing (such as Tukey window), and spectral analysis needed for the Horizontal to Vertical Spectral Ratio (HVSR) method. These functions are important for converting microseismic data from the time domain to the frequency domain, which is the basis for interpreting local site effects. GNU Octave is able to read and process data in text (.txt), CSV, or numeric matrix formats that are commonly used in microseismic data recording. With functions such as textread and matrix processing, Octave is very suitable for 3-component data manipulation (E, N, Z) which is common in microtremor studies. A complete explanation is given in the microseismic processing flow diagram using HVSR (Horizontal to Vertical Spectral Ratio) analysis shown in Figure 1. Microseismic data was taken from data points taken in the Yogyakarta City area which is an earthquake-prone area.

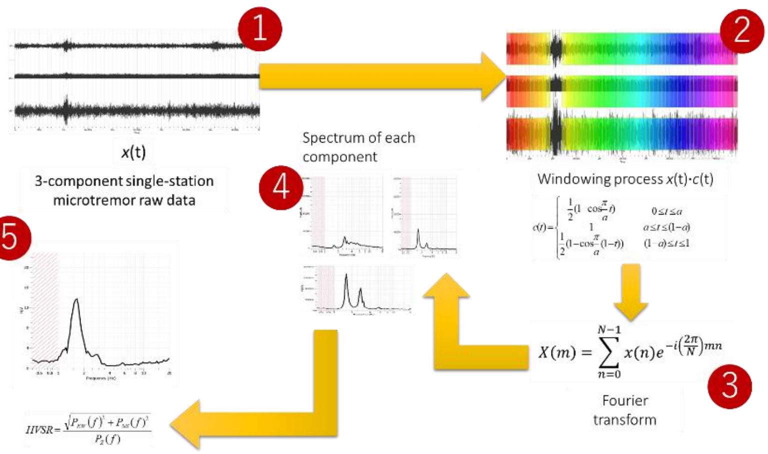

Figure 1. Research Design

Based on Figure 1, the first step is to display the 3-component signal data in the time domain. The second step performs the windowing process by multiplying the 3-component microseismic data with a window function. Each component is multiplied by the window function. The window function used is cosine tapered (Tukey Window). The windowing process uses a window width of 5% so that it can minimize edge effects or distortion that occurs during sampling (Sitti Fauziah Faradilla et al., 2024). Tukey window (cosine tapered) is used to reduce spectral leakage when performing frequency analysis (e.g. FFT). This window combines the advantages of rectangular and Hann windows, with a flat center and curved edges like cosines. The advantage is that it is flexible and can be adjusted between frequency resolution and leakage attenuation, making it suitable for signals that are not perfectly periodic, such as in microseismic data (Shibata et al., 2017). The third step performs a fourier transform to convert data from the time domain to the frequency domain using equation 1.

$$X(f) = \int_{-\infty}^{\infty} x(t) e^{-i2\pi ft} dt \qquad (1)$$

Equation (1) defines *X(f)* as the fourier transform of *x(t)*. Function *x(t)* is a function in the time domain and *X(f)* is a function in the frequency domain. The variables t is time and f is frequency. $e^{-i2\pi ft}$ is the kernel function, and $i = \sqrt{-1}$. The fourth step averages each windowing on each component. The fifth step uses the HVSR equation to process the 3-component signal data by comparing the signal in the horizontal component with its vertical component. Microseismic processing in this study will use GNU Octave software with coding made by researchers. In general, the HVSR equation used for microseismic processing is shown in equation 2.

$$HVSR = \frac{\sqrt{A_{EW}(f)^2 + A_{NS}(f)^2}}{A_Z(f)} \qquad (2)$$

With A_{EW}, A_{NS} dan A_Z are the amplitudes of the spectra of the east-west, north-south and vertical components, respectively. The resulting spectrum is used to determine the dominant frequency. The HVSR method eliminates the measurement of bedrock to obtain the sedimentary basin transfer function (Bodin et al., 2001). The basic principle of the HVSR method is the comparison between the amplitude spectrum of the horizontal and vertical components of the recorded seismic signal. The horizontal component is calculated as the square root of the sum of the squares of the two lateral components, while the vertical component is maintained in its original form. The HVSR value at each frequency is calculated from the ratio of the horizontal to vertical amplitude spectral. By utilizing this spectral ratio, the HVSR method is able to identify the local dominant frequency (fundamental frequency) which is closely related to the thickness and mechanical properties of the soil layer.

3. RESULT AND DISCUSSION

The programming made using the Horizontal to Spectral Ratio (HVSR) signal processing step of microseismic assisted by GNU Octave software is shown in Figure 2. Microseismic data describes ground vibration velocity in 3 components including north-south (NS), west-east (EW), and vertical (Z) directions in the time domain. The microseismic data used is research data taken in Yogyakarta City. The initial step shown in Figure 2 is the call of the signal library required for digital signal processing in GNU Octave. Next, the microseismic data from the three components (E, N, and Z) are loaded from text files that represent the east-west, north-south, and vertical directions, respectively. These data are then cut into short segments of 2048 samples (parameter P) to allow local frequency analysis through Fourier transform. In the segmentation process, the number of data windows (JW) is determined based on the shortest data length among the three components, to ensure uniformity of analysis. After that, the Tukey window function or cosine tapered window of 5% (r = 0.05) is applied to each data segment. The application of this window aims to reduce the effect of spectral leakage which can cause distortion in the frequency domain, especially at the edge of the signal. This windowing is important in the HVSR process because it allows for more stable spectral results and is representative of local geological conditions. Through this stage, the microseismic data that was originally in the time domain is prepared to be converted to the frequency domain, so that the spectral ratio between the horizontal and vertical components can be calculated accurately.

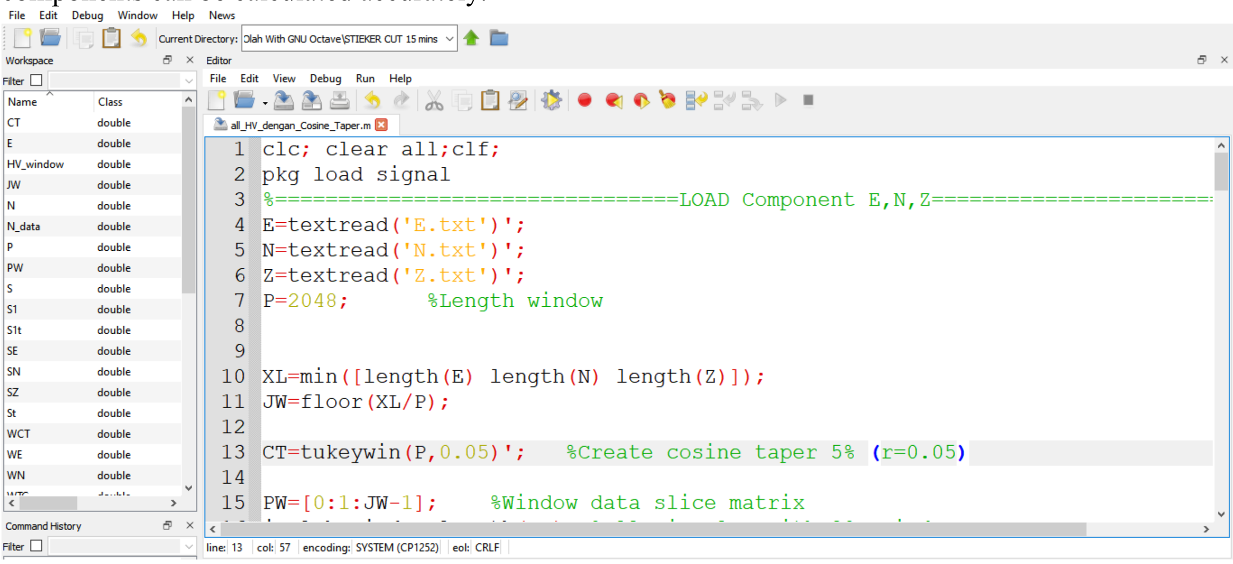

Figure 2. GNU Octave View

Programming in GNU Octave software begins with displaying data in the time domain as shown in Figure 3. The data begins with the txt extension. The pkg load signal command in GNU Octave is used to load the Signal Processing package into the Octave working environment. This package provides various functions related to signal processing that can be used to analyze and process signal data, both in the form of digital and analog signals.

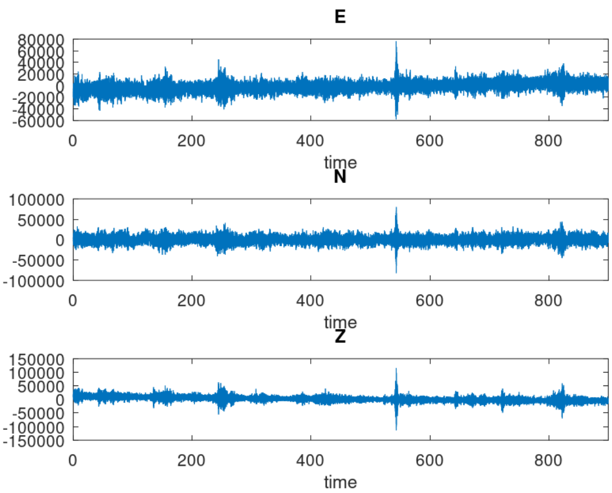

Figure 3. Time domain 3-component microseismic data

The display in Figure 3 was created using GNU Octave software with the coding E=textread('E.txt')'; N=textread('N.txt')'; Z=textread('Z.txt')' which means reading data with the txt extension. Next comes the windowing process, windowing is a technique for truncating a signal to a finite number of sample points. Simply put, a window of length N data is achieved by multiplying a signal containing N data by a cosine taper window containing N data. The windowing process is performed on each component. A view of the windowing process is shown in Figure 4. Before spectral analysis is performed, the microseismic signals shown in Figure 3 need to be further processed to minimize the effects of interference at the edge of the signal that can affect the Fourier transform results. One important stage in this processing is the application of a window function. Figure 4 shows the application of a 5% cosine taper function (Tukey window) to the microseismic signal to smooth the edge of the signal and reduce the effects of spectral leakage that can occur due to sudden signal cuts.

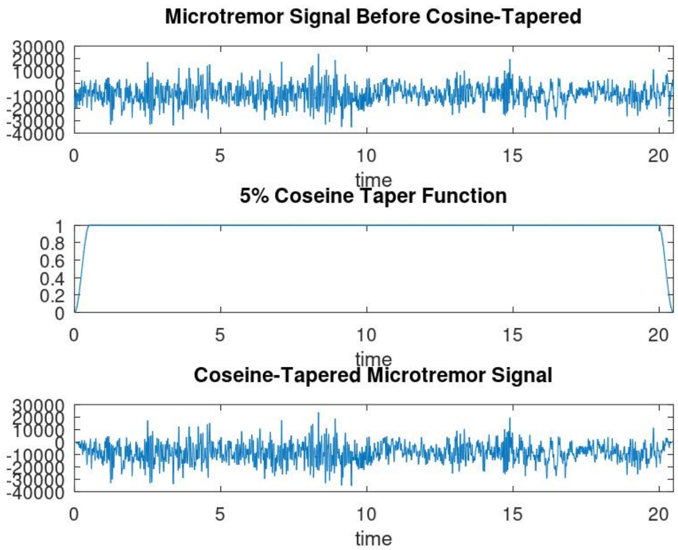

Figure 4. Cosine Taper Windowing Process

Furthermore, to display the windowing process as in Figure 4, the coding in the GNU Octave software is written with the coding CT=tukeywin(P,0.05)'; then WN=CT.*WN. Figure 4 not only shows the tapering process of microseismic signals in the time domain, but also has direct implications for the quality of the analysis results in the frequency domain used in the Horizontal to Vertical Spectral Ratio (HVSR) method. After the signal is tapered using a Tukey window of 5%, the signal becomes smoother at the beginning and end. This aims to avoid irregularities or sharp discontinuities at the edge of the signal that can cause spectral leakage, a phenomenon where frequency energy spreads outside its original band when the Fourier transform is performed. The application of windowing as shown in Figure 4 greatly determines the cleanliness and accuracy of the calculated amplitude spectrum.

The data in the window of each component will be fourier transformed so that the average spectrum of each component is obtained as shown in Figure 5.

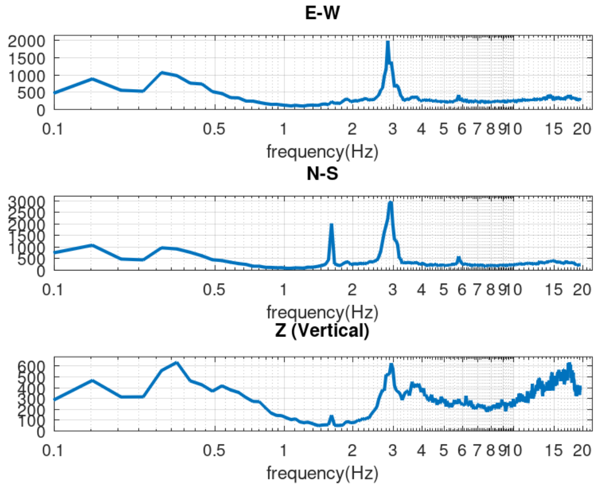

Figure 5. Average component spectrum in the frequency domain

The resultant horizontal component consisting of the north-south (NS) component and the east-west (EW) component is divided by the vertical component to obtain the HVSR curve shown in Figure 6.

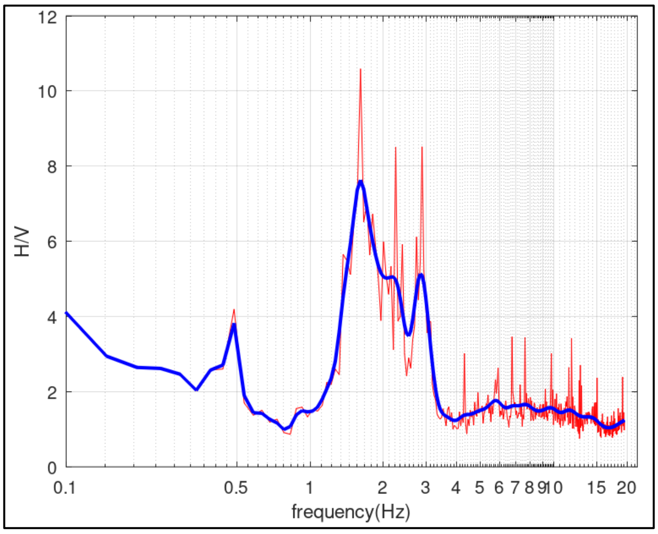

Figure 6. 3-component Microseismic Data Spectrum

The spectra shown in Figure 6 are based on the HVSR equation shown in equation 1.

$$HVSR(f) = \frac{\sqrt{S_{EW}(f)^2 + S_{NS}(f)^2}}{S_Z(f)} \tag{1}$$

Processing of the HVSR curve through the Smoothing process by applying the Konno-Ohmachi Equation shown in equation 2 (Beauval et al., 2006).

$$\mathrm{W}(f, f_0) = \left[\frac{\sin\left(log_{10}\left(\frac{f}{f_0}\right)^b\right)}{log_{10}\left(\frac{f}{f_0}\right)^b}\right]^4 \tag{2}$$

GNU Octave programming begins with displaying the 3-component signal data of north-south (NS), east-west (EW), and vertical (Z) directions in the time domain by writing a program like the following.

```
clc; clear all;clf;
pkg load signal
E=textread('E.txt')';
```

```
N=textread('N.txt')';
Z=textread('Z.txt')';
t=0:1/100:1/100*(length(E)-1);
figure
subplot(3,1,1);
plot(t,E); xlabel("time"); title("E"); xlim([0 1/100*(length(E)-1)]);
subplot(3,1,2);
plot(t,N); xlabel("time"); title("N"); xlim([0 1/100*(length(E)-1)]);
subplot(3,1,3);
plot(t,Z); xlabel("time"); title("Z"); xlim([0 1/100*(length(E)-1)]);
saveas(gcf,'Signal Mikroseismik ENZ.fig');
saveas(gcf,'Signal Mikroseismik ENZ.png');
```

The programming begins with reading and displaying data with textread coding in GNU Octave. Next, make the time interval as an independent variable with coding t=0:1/100:1/100*(length(E)-1) which means starting from the 0th data until the signal length is reduced by 1. Next, display the graph with plot coding, in this study a subplot is used to display the graph so that it becomes one graph display. Furthermore, each data component (ENZ) that has been read is multiplied by the window function. The windowing process used can be written as the following coding.

```
P=2048; %Length window
CT=tukeywin(P,0.05)'; %Create cosine taper 5% (r=0.05)
PW=[0:1:JW-1]; %Window data slice matrix
sum_window=length(PW); %All signals, with 20s window
s=0;
SE=0; SN=0; SZ=0;
for i=1:sum_window;
   WE=E((PW(i)*P)+1:(PW(i)+1)*P);
   WE=CT.*WE;
End
```

The coding starts by writing the window length to be used with the coding P = 2048; which means it has 2048 data or a data length of 20.48 seconds. Windowing used in this study uses the cosine tapered type or often known as the tukey window. The use of cosine tapered is used in this study because it gives similar results to the Gaussian window as shown by Orive-Miguel et al. (2019). After the microseismic signal is multiplied by the window function, the next step is to perform fourier transformation and smoothing. Programming to perform fourier transformation on each component can be done by writing the following coding.

```
[fft_component_E]=fft_64(WE);
[fft_componen_N]=fft_64(WN);
[fft_component_Z]=fft_64(WZ);
```

After the fourier transformation process is performed on each component, equation 1 is used to generate one HVSR curve as shown in Figure 5 for analysis. The HVSR curve analysis was conducted based on the dominant frequency and amplification values. The frequency and amplification data obtained are related to the local site effect, where the dominant frequency indicates the thickness of the sediment while the amplification indicates the magnitude of the earthquake wave amplification (Rahpeyma et al., 2016).

The results of data processing using GNU Octave are also compared with Geopsy software shown in Figure 7.

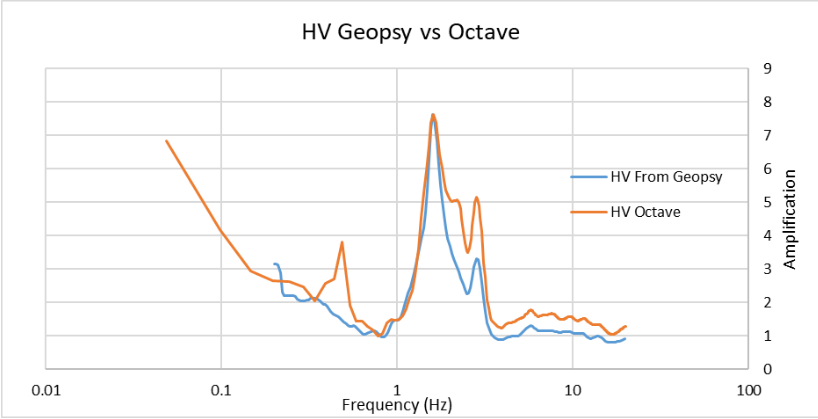

Figure 7. Comparison of Geopsy and GNU Octave Data Processing Results

The many peaks in Figure 7 indicate the presence of many sedimentary layers in the study area. (Kyaw et al., 2015). The results of GNU Octave data processing are shown by the orange curve. Meanwhile, processing using Geopsy software is shown by the blue curve. Based on the results of Figure 7, the processing results show the similarity of the HVSR curve. The dominant frequency on both curves is the same at a frequency of 1.59 Hz. However, the first peak of the HVSR curve is slightly different. The curve from GNU Octave shows a peak at a frequency of less than 1 Hz. Meanwhile, the Geopsy software curve does not show any peak at a frequency of less than 1 Hz. Based on GNU Octave processing, the research area consists of 3 sediment layers, while Geopsy processing consists of 2 sediment layers. From the comparison of the two software, researchers concluded that processing with GNU Octave software can be used as an alternative to microseismic data processing.

In addition to the dominant frequency, the HVSR curve shapes of both methods also show similar trend patterns in the mid to high frequency range (around 2–10 Hz), where the amplification value decreases gradually. This reflects the characteristics of the soil layer which gradually shows a transition to a stiffer medium below the surface. Although there are differences in some minor peaks and amplitude details, the similarity in the general pattern of the two curves strengthens the validity of the results of microseismic signal processing using GNU Octave as an alternative to Geopsy software. Overall, the similarity between the two curves in Figure 7 is evidence that the programming method with GNU Octave can be used as an efficient and accurate quantitative geophysical analysis tool. This provides opportunities for users, especially in academic environments or institutions with limited access to commercial software.

Programming made by researchers using GNU Octave software which is a duplication of Matlab. Programming can also be used as a way of processing microseismic data which usually only uses Geopsy software. GNU Octave was chosen because users can easily download and install for free (Lima et al., 2021). In addition, programming is also closely related to computational thinking. Computational thinking is a mathematical thinking pattern to solve problems by adopting the way programming works (Romandoni et al., 2016). Computational thinking is one of the most important skills to have in the 21st century (Jacob & Warschauer, 2018). The computational way of thinking in this research is through visualization of microseismic data processing. Data processing using microseismic in GNU Octave shows appropriate results. The appropriate results are because researchers compare GNU Octave microseismic processing data and Geopsy software has the same curve shape. This means that there is no error in the coding in GNU Octave that has been made. The impacts after using this microseismic data processing programming include 1) being able to understand signal processing from wave vibrations, especially for geophysics students; 2) having the ability to mitigate earthquake disasters through knowledge of signal processing results. This is supported by research Thamrin et al (2021) that teaches programming to vocational school students. The positive impact of the research is that vocational school students gain knowledge to develop their skills and understand how the software works.

Microtremors are constant vibrations at the ground surface with very small amplitudes. (Motamed et al., 2007). Microseismic data is ground vibration data consisting of body waves and surface waves (Satoh et al., 2001; Zhang et al., 2018). The results of microseismic data processing, namely dominant frequency and amplification, can be used to show local site effects. The results obtained are in the form of curves called HVSR curves that represent the geological conditions of the area. The shape of the HVSR curve is assumed to be related to the geological conditions of the study area. In addition, the HVSR curve shows the impedance contrast between the sediment layer and the bedrock layer (Thabet, 2019). Knowledge related to local site effects can also be used as a means of mitigating earthquake disasters in disaster-prone areas. In addition, by analyzing the HVSR curve, we will be able to assess or identify areas that have the potential to be prone to earthquake disasters. The research data is data from one of the earthquake prone areas in Indonesia, namely the city of Yogyakarta.

The dominant frequency identified in the HVSR curve plays an important role in understanding the dynamic characteristics of the soil layer, especially related to the potential for local resonance. In Figure 7, the dominant frequency of 1.59 Hz which is consistent in the results of GNU Octave and Geopsy processing shows that both methods are able to detect layers with significant impedance contrast to the bedrock. This dominant frequency value indicates the presence of a fairly thick sediment layer below the measurement location, which has implications for the potential for seismic wave amplification at low frequencies.

In addition to the dominant frequency, another important aspect obtained from the HVSR analysis is the spectral amplification value, namely the ratio between the amplitude of horizontal and vertical waves. A high amplification value indicates the potential for increased ground vibrations due to local resonance phenomena, especially if the dominant frequency value of the soil is close to the natural frequency of the building structure. The difference in the shape and height of the first peak in the HVSR curves from GNU Octave and Geopsy provides an illustration that the amplification results are greatly influenced by the sensitivity of signal processing to the uppermost or shallowest layer. The curve from GNU Octave which shows an additional peak below 1 Hz indicates the presence of a shallow soft layer that is identified more explicitly than the results from Geopsy.

Thus, the information obtained from the dominant frequency and amplification value on the HVSR curve is not only useful for identifying subsurface geological structures, but also plays a strategic role in seismic risk mitigation. In areas such as Yogyakarta City which have a high level of earthquake vulnerability, accurate HVSR interpretation can be used as a basis for designing development policies based on land vulnerability, while increasing preparedness for earthquake disasters.

4. CONCLUSION

This research has successfully visualized microseismic data using GNU Octave software to show how geophysical software works. Data from GNU Octave coding and Geopsy software were compared in this study. Both software show almost the same results. This shows that there are no errors in coding microseismic data processing. However, there is a difference in the first peak of the HVSR curve. The results of microseismic data processing, namely dominant frequency and amplification, can be used to show local site effects. HVSR curve analysis is used to assess or identify areas that have the potential to be prone to earthquakes. Visualization of microseismic data has many positive impacts on other researchers as a means of knowledge of how geophysical software works.

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