Early Result for Microtremor Characteristic Observation in Merapi and Merbabu

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Abstract. The arc magmatism and volcanic activity in Java are dominated by the subducting plate of Indo-Australian into the Eurasian plate. Merapi volcano is located in Central Java and known as one of the most active volcanoes in the world. Several studies have tried to estimate the magma reservoir zone in Mt. Merapi and suggested multiple layers of reservoirs with the shallow one at 1-2 km and a deeper at 6-9 km or 15 km. The Low-Frequency Passive Seismic is one method to analyze the frequency spectrum below the recording station. Previous related studies show a promising relation between hydrocarbon reservoir and higher amplitude at vertical component at a frequency between 0.1 – 6 Hz. An observation at the volcano sites have also been reported to display a different spectrum amplitude at the vertical component. This study exploited the same method in LFPS to analyze the frequency spectrum at Mt. Merapi and Mt. Merbabu. We use seismic data from the DOMERAPI temporary seismic network installed in the neighborhood of Merapi and Merbabu volcano. We analyze 53 broad-band seismometers data from October 2013 to mid-April 2015. We also add several stations from MERAMEX network instruments to compare spectrum analysis outside the Merapi and Merbabu volcano. We also removed some tele-seismic and regional events from the data to better analyze the LFPS signal. We have seen a higher amplitude in vertical component near Mt. Merapi and will proceed to analyze all stations.

1. Introduction
The Eurasian continent's southwestern most point is Java Island. The Indo-Australian plate's subduction underneath the Eurasian plate is critical to the region's arc magmatism and volcanic activity. Because of the tectonic setting covered by the Sunda Arc, megathrust earthquakes are common. From 50 km depth to North Java, the subduction rate between Australia and Indonesia is about 67 mm per year (Simons et al, 2007), and the slab dips from near-horizontal to a very steep angle (70°-80°) (Koulakov et al, 2007; Suhardja et al, 2020). Merapi volcano is located in Central Java and known as one of the most active volcanoes in the world, mainly due to the subducting activities in the surrounding area. Merapi volcano has had a total of 22 eruptions since the beginning of the twentieth century. One of the most notable eruptions occurred in 2010, when the lava dome production, gas emissions, erupted lava volume, and seismic energy released exceeded previous eruptions.
Volcanic earthquake classification has undergone many changes and improvement, the first and most recognized classification proposes that volcanic earthquakes can be divided into four types according to the location of their focus, their relationship to the eruptions, and the nature of the earthquake motion (Minakami, 1960 & 1974). The four types are A-type, B-type, explosion earthquakes, and volcanic pulsation. A continuous seismic signal that is observed during volcanic eruptions that lasts minutes to days in duration is called a volcanic tremor, although it is possible to observe it independently. This tremor which is also called a micro-tremor, mainly consists of surface waves and an irregular sinusoidal wave form. Based on study by Mogi (1963), volcanic earthquake sequences can be categorized into three main types, which are main shock-aftershocks sequence; foreshocks-main shock-aftershocks sequence; and swarm.

Storengy conducted Low Frequency Passive Seismic survey over a geothermal area on 2016, which was proven to detect the geothermal stream saturated area due to its fluid properties. The same response in terms of density and viscosity also was shown in hydrocarbon accumulation. According to Kazantsev et al (2017), since LFPS uses the micro-seismic as the natural diffuse seismic source to analyze the energy spectrum, volcanic tremors can be used as an additional natural source in geothermal context. Furthermore, similar technique used to monitor low frequency tremor associated to the magma chamber activity before eruption (Ferrick et al, 1982; Ripepe and Gordeev, 1999).

The focus of this study is microtremor’s characteristics in Mt Merapi and Merbabu. By using local earthquake tomography, it is observed that three active areas with high Vp/Vs are present in this location. The first region is a shallow zone which indicates an intense fluid activity, the second region is thought to be a 20 km depth below MSL pre-eruptive magma reservoir, and the last region is a magma reservoir zone at 30 km depth below MSL which is thought to be the supplier for the main reservoir.

2. Data and Methods
This research is conducted in the vicinity of the volcanoes of Merapi and Merbabu, Central Java. In this area, there is a DOMERAPI station network, consisting of 53 seismometer stations that are installed and scattered around the two volcanoes, with operating times starting from October 2013 to mid-April 2015 (Ramdhhan et al, 2017). However, for the data used in this study, only a few recorded events were taken for one week from 10 August 2014 to 17 August 2014. Also, several MERAMEX data networks around the study area were used to compare the results of spectrum analysis outside the Mt. Merapi and Merbabu areas.

In this study, using the passive low-frequency seismic method (LFPS), where the seismometer on the surface will record natural seismic waves originating from below the surface (Tenghamn et al, 2009). The recorded seismic waves will then be analyzed for their low-frequency spectrum to determine the characteristics of the seismic waves.

![Figure 1. DOMERAPI network around Mt. Merapi and Mt. Merbabu (Suhardja et al, 2020)](image)

We use bandpass filter from 0.1 – 6 Hz to minimize anthropogenic high noise and low-frequency ocean waves. Also, we minimize instrument response by normalizing the recorded signal. STA-LTA, an algorithm that uses short-term and long-term windows for obtaining the ratio of calculated average trace energy to trigger the algorithm activation, is applied to all the 3 components signal of MERAMEX.
& DOMERAPI stations in time domain to separate tremor and other wavefield by eliminating teleseismic and regional event. The algorithm requires deep knowledge of the overall trace energy from recorded signal to minimize false triggers and missing weak events.

Fast Fourier Transform is applied to accommodate frequency spectrum of recorded signal on all 3 components for Power Spectral Density technique (PSD). Then, we use the integral value under the PSD on all components to analyze the spectrum attributes. Vaezi & Van der Baan (2015) concluded that PSD technique was compensating the lack of STA-LTA algorithm on detecting weak events and false triggers in frequency spectrum and also helped designing bandpass filter better for analysis. The filter before applying STA-LTA algorithm is not optimal in dynamic noise environment. PSD technique from Vaezi & van der Baan (2014) is based on the concept of stronger spectral over a frequency band of seismic event than total trace energy to detect events in stationary noise conditions.

![Figure 2](image1.png)

**Figure 2.** (a) STA-LTA processing from station ME14. The signal was recorded on August 10th, 2014 (b) Spectral analysis from station ME14 of August 10th, 2014 recorded signal

Afterwards, we analyze both vertical and horizontal component of PSD attribute to identify the contrast response. Other attributes are frequency and amplitude response. V/H ratio applied on Dangel et al (2003), Saenger et al (2007) & Kazantsev et al (2017) is used in this study. The attributes analyzed on V/H ratio are peak and mean attributes as a comparison to recognize the difference in responses. The V/H ratio is calculated and mapped on limited frequency band. Next, the integral of power spectral density is analyzed both on vertical and horizontal component or we called it component energy.

![Figure 3](image2.png)

**Figure 3.** V/H ratio on station ME14 of August 10th, 2014 recorded signal

### 3. Result and Discussion

#### 3.1. Component Signal PSD Analysis

**3.1.1. Maximum Amplitude.** Based on figure 4, the distributed value of the red polygon has a low mark for range 0 - 0.234 except ME13 and ME23. ME13 and ME 23 has a high value between 0.338 - 1.88. High amplitudes correlate with the top of Merapi and Merbabu, and low amplitude correlates with the body of Merapi. The amplitudes have high attenuation on the body of mountains, in which the body consists of volcanic rocks such as tuff and pyroclastic. Then, the result of component vertical and horizontal has similar interpretation.
3.1.2. Maximum Frequency.

Figure 5 a) is the processing result in form factor of horizontal frequency distribution which located around Mt. Merapi and Mt. Merbabu. In orange box line is the station location around Mt. Merbabu, and the red box line is the stations located around Mt. Merapi. The values are varying from 0 – 8.63 Hz. It distributed evenly around stations. Near the ME16 station, shown as red, the frequency has the highest value than the surrounding areas. ME 16 frequency values is around 7.01 – 8.63 Hz, then the high frequency is distributed to the southern part, which are ME 23 and ME 29. ME 20, ME 17, ME 11, ME 10, ME 15 are surrounding the ME 16 station, and it shows different frequency value, around 0.749 – 1.2 Hz, shown as yellow color. On the Mt Merapi side, ME 22, ME 28, ME 34 and ME 24 surrounds the ME 23 and ME 29 stations. It also shows intermediate frequency values, varying from 0.749 – 1.2 Hz. From the frequency values, it shapes like boundaries surrounding the high values, more precisely around the ME 16, ME 23 and ME 29. Outside the boundary, are distributed thoroughly as low – frequency ranges, which shown as green to blue color.

Figure 5 b) is the result of data processing in the form of the distribution of vertical frequency values around Mount Merapi (green box line) and Merbau (red box line). In the figure, there are frequencies that have values varying from 0 Hz to 2.63 Hz and are evenly distributed throughout DOMERAPI & MERAMEX stations. It can be seen that the distribution of low-frequency values is spreading around Mt. Merbabu and Mt. Merapi area. To the north from Mt. Merbabu, the low frequency ranges from 0-0.241 Hz and surrounds Mt. Merbabu and several stations, ME10, ME11, ME12, ME13, ME16, and ME17. Then, the distribution of intermediate frequencies is spreading to the south and southwest directions of Mt. Merapi, ranging from 0.242-0.377 Hz. It can be shown at the following stations, ME 33, ME 36, ME38, ME39, ME41, ME42, ME49, and ME50. The high-frequency distribution is spreading over the area of Mt. Merapi to the southeast and northeast of the study area, ranging from 0.378-2.63 Hz. Several stations are in this high-frequency range, namely ME 23, ME 29, ME 34, and ME 40.

From the frequency value, it can be explained that the vertical frequency value is classified as low because the frequency is around 0-2.63 Hz, from the frequency value it is included in the thickness of the surface which has very thick sediment, it can be seen that this research area is in a mountainous area has a thick coating. However, it can be seen that in the distribution of vertical frequency values there are differences in frequency changes from low to high ranges, this can be identified as a change in lithology in the area, seen in the frequency change. at stations ME 02, ME 03, ME 15, ME 20, ME 22, ME 24, ME 27, ME 34, ME 35, ME 51, and ME 53. This could be the boundary layer between the sedimentary layer and the volcanic layer surrounding the station.
Figure 5. a) Horizontal Frequency Component, b) Vertical Frequency Component

3.2. Signal Energy Analysis

Figure 6. a) Horizontal Energy Component, b) Vertical Energy Component

Figure 6 a) shows the result of data processing in the form of the distribution of horizontal energy values, or the integral of the PSD of the horizontal component around Mt. Merapi and Mt. Merbabu. The map
is presented as blue to red color varying low to high values. The integral of power spectral density from horizontal component results varying from 0 - 1.04. The horizontal component is initiated to compare the vertical component result and showed anomalies relatively at the same locations. Unlike the vertical component, the horizontal component presents slightly lower values than the vertical component around station ME23, ME29, ME24, ME20, ME22, and ME28 varying from 0.168 - 1.04 inside the seismic network. Other stations relatively show much lower values outside the previous anomaly mentioned, ranging from 0 - 0.0448, except around ME13 and ME49 stations present slightly higher values than vertical component, varying from 0.168 until 0.373. At the less dense of seismic network, several anomalies are present at the northeast part near ME03 and ME53 stations and the southeast part outside ME51 and ME40 stations while the south western part is closed to ME33 and ME49 stations. The north eastern and south eastern part distributes evenly-values varying from 0.168 - 0.7. Compared to the vertical component, the south western to western part distributes higher values at ME33 and ME49 stations than the vertical component varying from 0.168 - 0.373.

Figure 6 b) shows the result of data processing in the form of the distribution of vertical energy values around Mt. Merapi (south) and Mt. Merbabu (north). The distribution of the values of energy varies from 0 – 1.04. Based on the figure, the values in Mt. Merbabu area tend to increase as it goes from west (ME 06) to the east (ME 02) with the highest value distribution in the area (around 0.112 – 1.04) is located in the north eastern part surrounded by ME 02, ME 03, and ME 53 stations. Meanwhile in Mt. Merapi area, the high energy values are distributed in two main parts. The first part is located in the centre, mainly around ME 23 & ME 29 stations and surrounded by ME 22, ME 24, ME 28, and ME 34 stations with distribution varying from 0.372 – 1.04. The second part is located in the south eastern part, close to ME 40 and ME 51 stations with distribution varying from 0.112 – 1.04 and is distributed more evenly than the first part. Aside from the high energy distribution, the area is distributed thoroughly as low – frequency ranges (around 0 – 0.111), which shown as green to blue color.

3.3. V/H Ratio Analysis
In figure 7 a), we could know that the maximum V/H frequency distribution is around 0-6.83 Hz. Distribution in Mt. Merapi and Mt. Merbabu are having low - frequency range values. Low frequency distribution indicates pyroclastic rock lithology in that area, because pyroclastic rock has a high attenuation characteristic.

In figure 7 b), we could know that the maximum V/H ratio value is around 0 – 18.6 Hz. The distribution in Mt. Merapi and Mt. Merbabu has distribution variation from low, intermediate, and high. Based on literature, the sub – surface lithology distribution for the high V/H ratio in Mt. Merapi is caused by solid and dense rocks. For the mean V/H value has similar distribution with V/H ratio.
4. Conclusion
From the maximum amplitude PSD attribute, we can see similar pattern from the horizontal and vertical component based on qualitative interpretation. There’s some kind of boundary consist of low amplitude that surrounds the high amplitude, but the maximum frequency PSD attribute have a different pattern. Qualitatively, the energy signal PSD attribute have similar pattern to the maximum amplitude PSD attribute. The energy signal PSD attribute have similar pattern between horizontal and vertical component on Mt. Merapi area, but on the Mt. Merbabu area, it has different pattern between horizontal and vertical component. From the ratio analysis, there’re no pattern similarity between V/H ratio, V/H frequency, and V/H mean ratio. From the result, the best attribute we could purpose for this research is maximum amplitude PSD attribute and maximum energy signal PSD attribute.

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