Identification of underground river with microtremor method in Dersono karst area, Pacitan

A S Bahri¹, M I U S Abdullah¹, S A Aliyan¹, M S Purwanto¹, A Widodo¹, A Hilyah¹, M H M Fajar¹, P V Hardyani¹, Sunardi², E W Alita³, M Rahmat¹ and I Nurfitriana¹

¹Geophysical Engineering Department, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia
²PPI Madiun, BPSDM Transportation, Ministry of Transportation, Madiun, Indonesia
³Regional Research and Development Agency of Pacitan Regency, Pacitan, Indonesia

e-mail: syaeful_b@geofisika.its.ac.id

Abstract. Many islands in Indonesia are formed due to the lifting of the seafloor which forms limestone lithology and forms karst morphology. The karst region has a large freshwater potential that accumulates in the underground river system. The existence of an underground river system as a water reservoir is very important in fulfilling the needs of the community, especially in island countries such as Indonesia that have many karst regions. Research to map the position and distribution of underground rivers is carried out by applying geophysical methods. One of the geophysical methods applied is the microtremor method. The working principle of this method is the identification of underground rivers based on Particle Motion method and Time Frequency Analysis (TFA). That analysis resulted in the particles movement direction that perpendicular to the vibration source which is identified as the underground river. The existence of the underground river is then validated based on the TFA parameters of the underground river karst region. The results of the Particle Motion analysis at the research location show the character of the river flow pattern that has a Northeast-Southwestern orientation, and based on TFA there is amplitude continuity in the river flowed area with a frequency range of 4 - 5 Hz and an amplitude of 2,000 dB – 20,000 dB on component Z (vertical).

1. Introduction
Many islands in Indonesia are formed due to the lifting of the seafloor which forms limestone lithology and forms karst morphology. In the southern part of Java, famous for Gunung Sewu which has a karst morphology, Gunung Sewu Mountain area stretches from Parangtritis to Pacitan with an area of approximately 1,400 km² [1,2]. The karst region has a large freshwater potential that accumulates in the underground river system. The existence of an underground river system as a water reservoir is very important in fulfilling the needs of the community, especially in island countries such as Indonesia that have many karst regions. Pacitan Karst area has underground river potential which is the resilience of water resources.

The study was conducted in the Dersono region which is one of the areas that is often hit by drought in Pacitan. Dersono karst region is formed from reef limestone units, layered bioclastic limestone, and napal which are part of the Middle Miocene to Late Miocene Wonosari Formation [3]. The only source of water used by residents for their daily needs is the source of water that appears on the edge of the Maron river in the western part of the village. Based on the results of field surveys that have been conducted, caves or luweng (vertical cave) are found scattered in several locations in the village of...
Dersono. This indicates the existence of underground river flows that are interconnected between these vertical caves. 

The method used in this study is the application of one of the geophysical sciences, namely microtremor. Microtremor exploits natural events and not short-duration events such as earthquakes and explosions [4,5]. Microtremor was applied to determine the dynamic characteristics (dominant frequency and amplification factor) of the soil layers spearheaded by Kanai and Tanaka in 1954 [6,7]. This method is applied because underground streams can be interpreted as a continuous vibratory source that has the characteristic microtremor data. The microtremor data includes frequency, resultant movement of particles and amplitude [8]. In this study the microtremor data generated will be processed using two methods, namely the Particle Motion method and time frequency analysis (TFA). In this study the Particle Motion method is used to detect continuous vibrating sources in the area which will later be interpreted as underground rivers. Furthermore, TFA is used to analyze the frequency recorded during the measurement time so that it can be used to identify the character of underground rivers at the study site.

2. Methodology

The research location is in Dersono area, Pringkuku District, Pacitan Regency. The location of this study is 226 km from the city of Surabaya and is included in the Pacitan karst area which is in the southern part of the island of Java. The location of data collection in this study was divided into two locations. Following is the acquisition design at locations 1 and 2, as shown in Figures 1 and 2.

![Location 1 Acquisition Design](image1)

**Figure 1.** Location 1 acquisition design

![Location 2 Acquisition Design](image2)

**Figure 2.** Location 2 acquisition design

At location 1 measurements were made in the area around Luweng Tangggung to a water source located near the Maron river. The location of Luweng Tangggung is at the MT-2 point which is located
3. Results and Discussions

3.1 Particle Motion

Particle motion data processing is carried out to identify the direction of the vibratory source, where in the study area is indicated as an underground river flow. This is consistent with the initial hypothesis that river flow is a continuous source of vibration so that trend particle motion can be used to estimate the direction of underground river flow. This is due to the underground river flow that is the source of the vibration causing the movement of particles away from that point so that the trend particle motion will have a direction that is perpendicular to the direction of the underground river flow at that point.

3.1.1 Particle motion in location

In particle motion data processing at location 1, there are three calibration points taken during the study. These are namely the MT-2 point which is located directly above the luweng in the field, MAL point which is above luweng but the measurement is on the hill, and MT-6 point which is above luweng and adjacent to the surface of the ground water that comes out of the tube. These three points are taken as the reference for each condition flowed by the underground river below the measurement point. Following are the results of particle motion data processing at the three calibration points.

Figure 3 show that the resultant particle motion is interpreted by black lines which are vibrations that appear during the time span of measurements overlapping in the middle so that it can be analyzed that the resultant direction of the particle's motion is centered. This is due to the calibration points of the source of vibrations originating from the underground river just below the point of measurement so that the direction of particle motion does not have a dominant and centered direction at that point. In addition to the three calibration points above, at location 1 measurements were also made at nine other points around the luweng location to estimate the direction of underground river flow at that location. Here are the results of processing particle motion at these nine points.
3.1.2 Particle motion in location 2

Particle motion processing at location 2 has a difference with processing at location 1. This is due to the absence of certainty of the existence of underground rivers at that location so that measurements cannot be made at the calibration point for underground river systems at site 2. However due to the research of locations 1 and 2 are relatively close together (± 1 km) then the results of particle motion calibration at location 1 can still be considered relevant. This is because if there is an underground river at location 2 it will tend to be like the underground river system at location 1. Figure 5 in the following presents the resultant movement of the resulting particle processing data at location 2.
3.1.3 The direction of underground river flow

In the particle motion method, it can be estimated the direction of underground river flow based on the combined direction of the resultant particle motion at each location. The following is the result of plotting the resultant direction of each point and the approximate direction of underground river flow at locations 1 and 2.

Figure 5. Resultant particle motion at the measurement point at location 2

Figure 6. Estimated direction of underground river flow based on resultant particle motion at location 1
Figure 6 shows the correlation between the resultant particle motion with the direction of the flow of the underground streams that are around it. In addition, in Figure 6 we can see that the points MT-1 and MT-7 have a resultant direction that is centered to resemble the response shown at the calibration point. This is because at both points, they are located relatively far from the vibrating source that originates from the underground stream, so the movement of the particles is not affected by the underground river flow at that location. This is supported by the correlation of points around MT-1 and MT-7 which show the resultant particle motion parallel to the two points. This further indicates the absence of vibrating sources originating from MT-1 and MT-7 that exceeds the vibratory source Originating from the underground river system. At location 1 the underground river flow originates from MT-2 and finally appears at MT-6 before finally joining the Maron river.

The same principle as at location 1 is also applied at location 2 to produce an estimate of the direction of underground river flow as in Figure 7. The direction of underground river flow at location 2 has a relatively different direction when compared to location 1. If at location 1 the direction of flow tends to have an east-west direction while at location 2, the direction of flow tends to have a northeast-southwest direction. This is in accordance with the direction of the Grindulu fault which is the cause of the existence of a weak zone in the area.

3.2 Time Frequency Analysis
The time frequency analysis (TFA) process is carried out with Geopsy software by analyzing the three microtremor signals at each point in the frequency range according to the results of the HVSR processing over time. Following are the TFA results at several points representing the research location.
Figure 8 shows the results of TFA processing at the M10 measurement point located in the hilly area of the study site. This point was chosen to be a calibration of TFA results in hilly areas because based on particle motion analysis shows this point is one of the points that is passed by underground river flows. The results of TFA processing on M10 show the existence of continuous amplitude values in the 4 - 5 Hz frequency range. This value then becomes validation of the existence of underground rivers at that location because it matches the characteristics that have been previously defined through research [11]. The same analysis is also carried out at point M14 which represents the field area and M20 which represents the study site above luweng.
Based on the results of TFA processing at point M14 it is then found that the result of continuous amplitude in the same frequency range as point M10, which is in the range of 4 - 5 Hz. This proves that underground rivers at the study site have the same frequency range values at various locations. However, different results are seen in the continuous amplitude value at point M14. This can be observed in Figure 9 which illustrates the results of TFA processing at M10 showing a continuous amplitude value at frequencies of 4 - 5 Hz ranging from 2,000 – 6,000 dB, but at point M14 the continuous amplitude value at the same frequency range has a value of nearly 20,000 dB. This magnification of the amplitude value occurs because the field area has a thicker layer of soil when compared to hilly areas. This causes a change in the wave propagation medium from the hard rock layer to the softer layer so that one of the wave properties applies that will experience amplitude amplification when moving from a dense medium to a less dense medium. Almost the same amplitude value also occurs in the measurement results at point M20 as shown in Figure 10.
Figure 10. TFA results on M20

Figure 10 shows the value of the TFA processing at point M20 which is located just above the luweng. TFA processing results at point M20 show continuous amplitude values in the same frequency range of 4 - 5 Hz as seen at points M10 and M14. However, at the M20 point the resulting amplitude has a value of around 20,000 dB as at point M14. This is because point M20 has a location character that is almost the same as point M14, which is in a field with a thickness of topsoil layer thicker than the hilly area.

Based on the results of TFA processing at the study site, it is found that the frequency value always has a continuous amplitude. This continuous amplitude indicates the character of underground river data at the study site in general. The sample results shown above are representative of each location which generally consists of hilly areas, fields, and above luweng locations. Based on the three images, it can be observed that the amplitude of the underground river at the study site has a continuous value at a frequency of 4 - 5 Hz with an amplitude value ranging from 2,000 to 20,000 dB. So that this value can be concluded as a character of frequency and amplitude data on underground streams at the study site.
4. Conclusions
Based on the observation and analysis conducted in this study, primary conclusions can be drawn as follows:

1. The results of the mapping of underground rivers based on resultant analysis of particle motion, shows the flow of the river at location 1 has East-West orientation lead to Maron river and at location 2 has a Northeast-Southwest orientation.
2. Based on the results of time frequency analysis (TFA), the vertical component (Z) becomes a component to see the character of the amplitude continuity of the TFA results. This is because the vibrations generated by the river flow create a continuous amplitude of the surface with an amplitude value of 2,000 – 20,000 dB and in the frequency range of 4 - 5 Hz as a typical value of underground rivers in the study area.

Acknowledgements
We are grateful to the many people who have contributed to this research. Special thank go to the Director of Research and Community Service Ministry of Research, Technology and Higher Education (DRPM Kemenristekdikti) for the financial support provided to this research.

References
[1] Lehmann, H. (1939). Morphologische Studien auf Java. Geographische Abhandlungen, 3 Reihe, Heft 9.
[2] Van Bemmelen, R.W. (1949). The Geology of Indonesia Vol-IA. Government Printing Office, Virginia, USA.
[3] Sitorus, T., Toha, B. and Sudarno, I. (1992). Peta Geologi Lembar Surakarta-Giritontro, Jawa, Skala 1:100.000. Pusat Penelitian dan Pengembangan Geologi, Bandung, Indonesia.
[4] Seht, M. Ibs-von. and Wohlenberg, J. (1999). “Microtremor measurement used to map thickness of soft sediment”. Bulletin of Seismological Society of America 89(1):250-259.
[5] Sitorus, N., Purwanto, M.S. and Utama, W. (2017). “Analisis nilai frekuensi natural dan amplifikasi desa Olak Alen, Blitar menggunakan metode mikrotremor HVSR”. J. of Geosaintek ITS 3(2):89-92.
[6] Kanai, K. and Tanaka, T. (1954). “Measurement of the microtremor I”, Bulletin of the Earthquake Research Institute 32(2):199–209.
[7] Arifin, S.S., Mulyanto, B.S., Marjiyono and Setianegara, R. (2013). “Penentuan zona rawan guncangan bencana gempabumi berdasarkan analisis nilai amplifikasi HVSR mikrotremor dan analisis periode dominan daerah Liwa dan sekitarnya”. J. of Geofisika Eksplorasi 2(1).
[8] Kurniawati, D., Maryanto, S. and Wasis (2013). Penentuan Pusat Aktivitas Hydrothermal Daerah Cangar Jawa Timur Berdasarkan Analisis Pergerakan Partikel (Particle Motion). Universitas Brawijaya, Malang, Indonesia.
[9] Cohen, L. (1995). Time-Frequency Analysis. Prentice Hall, New York, USA.
[10] Kumar, P. and Foufoula-Georgiou, E. (1994). Wavelet Analysis for Geophysics Application. Academic Press, San Diego, USA.
[11] Bahri, A.S., Chemistra, P., Utama, W. and Widodo, A. (2018). “Characterization of microtremor for the identification of underground rivers at Kedung Banteng, Pacitan, Indonesia”. Conf. EAGE-HAGI 1st Asia Pacific Meeting on Near Surface Geoscience and Eng., Yogyakarta, Indonesia, Apr. 9-13.