Study of Groundwater Pathway in the Shallow Bedrock Area using Very Low Frequency Method

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Abstract. In the hard rock and thick forest area, the use of active geophysical method for groundwater exploration is relatively difficult. In this study, very low frequency survey method has been successfully used to explore the possibility of the groundwater pathway in the hard rock area. The very low frequency method used T-VLF with the reding stations of 2 m and 5 m. The data then processed using inhouse software. As the results, the VLF model shows the conductive zones at several sites that are observed at the depth of less than 10 m. These conductive zones are indicating as the zone of water pathway. The study area is dominated by the non-conductive zone which is indicating that there is no possibility of water pathway. Generally, the water pathway has been found between the hot spring and small lake at the southeast of the study area.

1. Introduction
Water in the hard rock area moves through the crack system of the fracture gap, while in soft sediment areas the groundwater moves through the grain pores. The water pathway relationship needs to be clearly known, because in the hard rock area the underground water current can sometimes be parallel horizontally but the flow is opposite, it can even cross terraced not interconnected. Based on this pattern, the relationship between water current and other crack system becomes difficult to determine. The effort to determine the crack zone is important in order to predict the source of water in the hot spring area, due to it is the geothermal resources [1].

The geophysical methods are commonly used to investigate the subsurface anomaly from the deeper target such as in the oil and gas industry [2] until till to the shallow target. In the shallow target, the geophysical methods have been used for the several purposes such as for the contaminated groundwater investigation by heavy metal [3] and by the seawater intrusion [4,5]. The geophysical method, especially geoelectrical resistivity is also more famous to investigate the slide zone of the dip hill area [6] and the lanfill area [7].

One of the geophysical method that can be used to find the presence of groundwater in limestone or other sediment through the conductivity of the rocks is the electromagnetic method, which is a method in geophysical exploration which is generally used to search for conductive materials [8]. The method depends on the signal source as well as the variation in the receiving sensor. The Very Low Frequency (VLF) method is one of the electromagnetic methods where the signal source comes from a low-frequency military radio transmitter with high penetrating power which was originally used for navigation and communication of submarines at sea.

The geophysical method, which is an indirect method, can be applied in the search for possibility of groundwater pathway in the hard rock area. One of the methods in geophysical exploration that is generally used to search for materials that have high conductive properties is the VLF (Very Low
Frequency) method. This method is a geophysical method that is fast and environmentally friendly and is a passive electromagnetic method that works in the 15-30 kHz frequency band [9].

The hot spring in Rokan Hulu, Indonesia is found about 30 years ago. Now, this hot spring is used by the community for the tourism attraction. In this research area, one of the interesting groundwater occurrences is from hot spring which flows through around the hard rock area. This become the interesting to search where exactly the source of the water of this hot spring.

In this study, the use of very low frequency survey was carried out to recognize the pathway of water in which the hard bedrock was visible everywhere at the surface in several sites. This study is expected to detect the source of groundwater which is recharging the hot spring with the constant rate along this time.

2. Methodology

The VLF method is an electromagnetic method whose signals use radio waves with a frequency of 15-30 kHz. The VLF electromagnetic field is generated by a radio wave transmitter with a large power, namely 100-1000 KW with a frequency of 15-30 kHz and a wavelength of 10-20 km.

The working principle of VLF is that the transmitter emits a signal in the form of primary electromagnetic waves through the ionosphere. The components of the primary electromagnetic field can be thought of as waves traveling horizontally. If there is a conductive medium below the surface, then the magnetic field component of the primary electromagnetic wave will induce the medium so that it will cause an induced current (Eddy Current) in other words if the material is conductive when subjected to a moving magnetic field it will induce eddy currents (the greater the eddy current the greater the charge density). The electromagnetic field that propagates on the rock conductivity $\sigma$, permittivity $\varepsilon$ and permittivity $\mu$ applies to Maxwell’s equations written in the frequency domain.

![Figure 1: The location of VLF survey](image)

In this research, the T-VLF that is produced in France was used in the collecting data. There were four survey lines conducted in the thick secondary forest. The data reading interval was 6 meter length with the total survey length was 2800 meter. The VLF survey was concentrated in between the hot spring and the lake at the southern part of study area. Figure 1 shows the location of the VLF survey and the hot spring. In the map, the small lake is found at the southern part of the study area.
3. Results and Discussion

The results of data analysis generated by VLF were analyzed based on the characteristics of the material's conductivity value. The conductivity characteristics of this material are referred to the possibility of water accumulation zone. The results of this analysis will produce data on groundwater accumulation or groundwater zone at the study site.

The VLF surveys were conducted on the hard rock of the hill just afterward the hot spring. The Line 1 and Line 2 were adjusted following to the dip hill direction. While the Line 3 and Line 4 were conducted on the hill between the small lake and the hot spring. In the Figure 1, the intersection of tilt and elips produces the conductive zone (colored red). The conductive zone is represented by the blue color, while the red color is representative of more resistive zone. This zone is believed as the accumulation of groundwater at the shallow depth until 30 m deep. The line 1 was conducted just beside the hot spring with the distance about 20 meter from it. So, the conductive zone was appear from the ground surface to the 30 meter deep.

![Tilt vs Elips (top) and 2D VLF model of line 1](image)

**Figure 2.** Tilt vs Elips (top) and 2D VLF model of line 1

Figure 3 shows the Line 2 which is conducted about 200 meter from the line 1 and parallel to it (see map in Figure 1). In the survey line 2, the conductive zone (colored red) is appeared ad the left side of the nonconductive zone (colored blue). However, the conductive zone that is appear in the Figure 3 is still the same extended conductive zone in the Figure 2.

The other two survey lines were conducted further to the southward (see Figure 1). The survey line 3 and Line 4 were conducted with a little bit difference direction with the survey line 1 and survey line 2. Furthermore, the survey line 3 and line 4 have the longer spreading that is about 900 meter length which is their orientation almost to east and to west, respectively.

Figure 4 and Figure 5 show the VLF model of survey line 3 and survey line 4, respectively. The survey line 3 and survey line 4 have opposite direction. In these survey lines, the resistive zone is dominating for the whole zone at two survey line. This is because the two line were conducted on the hard rock of metasedimentary rock.

The conductive zone (colored red) were appear at the same position (at the east part of these lines). This is indicating that the conductive zone is connected each other. From the four very low frequency
models, it can be clearly seen that the conductive zone is connected from the zone around the small lake to the hot spring zone.

**Figure 3.** 2D VLF model of line 2

**Figure 4.** 2D VLF model of line 3

**Figure 5.** 2D VLF model of line 4

4. Conclusion

This investigation is the series of study that was conducted at the hot spring area in the Rokan Hulu, Indonesia. The condition of subsurface in the area of the hot spring in term of the possibility of crack zone was observed using very low frequency method. In the study area, the dominant bedrock is consisted of metasedimentary rock. The source of water for the spring is predicted coming from the small lake at the southeast of the hot spring. This is proved by the occurrence of the possibility of conductive zone at the very low frequency model which is interpreted as the possibility of crack zone of the hard rock.

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