SEGJ The 13th International Symposium TOKYO 2018

Groundwater exploration in volcanic morphology using geophysical schlumberger resistivity method, in Jeneponto, South Sulawesi Province.

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ABSTRACT

The research area is located in Camba-Camba Village, Batang, Jeneponto, South Sulawesi Province, Indonesia. This area is included in the the Indonesian Government ‘development acceleration program for underdeveloped regions’. This research area shows a flow ridge volcanic morphology consisting of volcanic breccia, tuffaceous sand, and laharic clay deposit from Lompobatang Volcanic Formation. The geological condition leads to a scarcity of groundwater in the area, which makes looking for a great groundwater source is challenging. On the other hand, such a groundwater source is needed to fulfil the water demands of plantation and rice field irrigation, particularly in the dry season. The geoelectric or resistivity method was used in this study to determine the location and depth of groundwater aquifers. The resistivity method used was the vertical electrical sounding (VES) "Schlumberger" method which aims to identify the variation of subsurface rocks resistivity value against depth. Through an inversion resistivity modeling, the true resistivity value in this area ranges from 0.87 to 6117 Ωm. There are five groups of subsurface rocks that could be identified based on these values, namely claystone aquiclude, shaly sand aquitard, tuffaceous sandstone aquifer, volcanic breccia aquitard-aquifuge, and lava aquifuge. Each group, respectively, showed a resistivity value of 0.87-10.63 Ωm, 12.74-22.91 Ωm, 18.83-58.25 Ωm, 62.46-159.5 Ωm, and 414-6117 Ωm. Based on the results of the correlation and modelling of these five groups, a drilling site location was set near the JPT 02 resistivity measurement point, where the model showed an aquifer at the depth of 50 meter. The presence of this aquifer was confirmed by the drilling.

KEY WORDS: Resistivity method, groundwater exploration, volcanic morphology, tuffaceous sandstone

INTRODUCTION

In 2017, the State Minister for Villages, Acceleration of Development in Underdeveloped Regions and Transmigration of Republic of Indonesia published Ministerial Instruction No.1 of 2017 on “priority activities of the ministry”. Regarding to this instruction, one of the priority programmes in order to develop the underdeveloped regions is reservoir construction and development of other small water containers. For this reason, the Directorate General of Facilities and Infrastructure Improvement has allocated funding for building reservoirs. One of the reservoirs will be build in Camba-Camba Village, because deep groundwater wells are needed as a water supply during dry season. Previously, geophysical resistivity surveys have been conducted in this area by appointed contractor followed by drilling a 120-meters-depth well. Pumping test was conducted on this well but the water only flowed for approximately 2 hours. Our team were appointed to evaluate the result of previous work, and to conduct new data acquisition and determine the more potential locations for subsequent drilling. Resistivity survey has been conducted to identify the subsurface geology as well as groundwater aquifers.

The morphology of the study area is a volcanic lava flow ridge, consisting of breccia, sand deposits and clay of Lampobatang volcanic-laharic sediment (Fig. 1) (Sukamto and Supriatna, 1982). Hydrogeological structure of an area is strongly controlled by its morphology. Therefore, it is challenging to draw the hydrogeological structure in typical complex morphology as in Camba-Camba village. Furthermore, identifying the distribution of groundwater aquifers in volcanic area is also difficult. These two main issues are likely to lead to difficulties and failures in ground water exploration in the research area. Therefore, a well knowledge on geology as well as accuracy on running the geophysical survey are the key for the project to be succeed. Therefore, prior to the data acquisition, initial investigation on the geological setting of the area was undertaken in order to determine the arrangement of acquisition process and how subsurface interpretation would be performed (Hermawan and Putra, 2016).

METHODS

Geophysical survey used for groundwater exploration has to consider the geological conditions of the area (i.e, geological structure, morphology and lithology). Resistivity method, particularly vertical electrical sounding (VES) “Schlumberger” configuration is

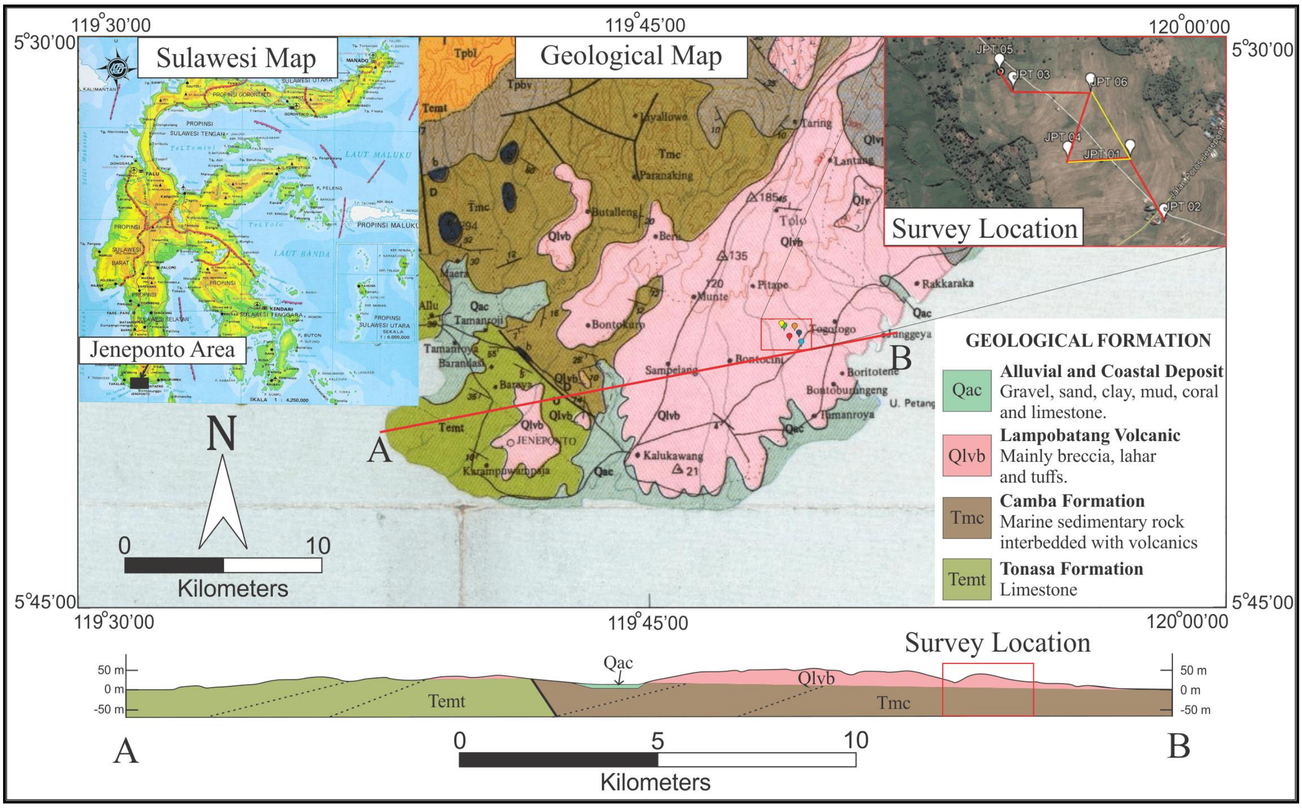


Figure 1. Geological map and cross-section of the research area (Sukamto and Supriatna, 1982). Inset is the map of Sulawesi Island and the research area is marked in black box in the southern arm of the island, labelled as Jeneponto area. In the geological map, it is shown that the research area (delineated by red-outlined box) is located in quartenary Lampobatang volcanics deposit. The resistivity data is gathered from six acquisition points and their distribution is shown in the survey location map (upper-right corner).

commonly used for ground water exploration. This method enables us to measure the variation of rock resistivity value to depth. Several factors, including porosity, metallic mineral and water content, control this value (Telford et al., 1990).

Resistivity survey configuration consists of two current electrodes (C) and a potential electrode (P) placed symmetrically in between two current electrodes. In Schlumberger VES measurement technique, we change the distance of C related to P to obtain the desired depth range. The change has to be made on both sides with fixed P position (Fig. 2). The P will be moved when the distance between P and C is large enough to maintain a measurable potential (Telford et.al., 1990). the targeted depth of this research area is 150 meters considering the geological condition. In order to meet the targeted depth, the two C have to be placed 500 meters apart.

$$\rho_a = \frac{\pi(b^2 - a^2)}{2a} \frac{\Delta V}{I} \quad (1)$$

Where : ρ_a : Apparent-resistivity (ohm.meter)
a : Half distance between P electrode (meter)
b : Half distance between C electrode (meter)
ΔV : Potential difference (volt)
I : Current (ampere)

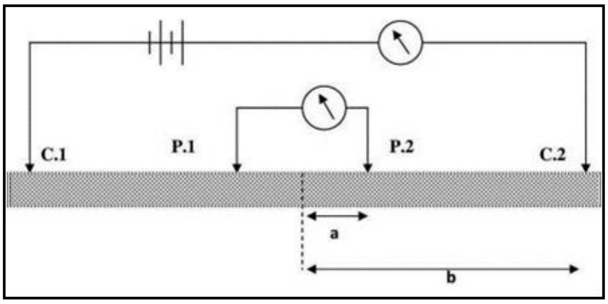


Figure 2. VES configuration Schlumberger resistivity survey (Telford et al., 1990).

The observed resistivity value in the field is called apparent-resistivity (ρ_a) acquired from equation 1. The value will be analyzed using inverse modeling method to get true-resistivity data against depth. The method can be done manually by plotting the measured values (ρ_a vs b) into double logarithmic paper and calculated using standard curve modeling. This technique is called partial curve equation technique (Zohdy, 1989). Nowadays, the technique can be done automatically using computer software, such as IPI2Win and Progress.

GEOPHYSICAL DATA

Six acquisition points have been used to evaluate the hydrogeological structure of the research area and to determine the potential locations for subsequent drilling. The acquisition points must be within a radius of 2 kilometers from the reservoir construction plan area. The acquisition location were made across the relative direction of north-south and west-east (Fig. 1). During data acquisition, its important to inspect surrounding structural geology, such as dipping layer and possible faults, as these features may affect the quality of the data taken. This investigation will also help us to build a reasonable subsurface model (Zohdy, 1969). It can be observed in the field that the lithology is dipping towards southeast, so the acquisition arrangement should be parallel to the strike which is northeast-southwest. The resistivity measurement data are then processed using IPI2WIN 3.0.1 which can perform forward modeling automatically, the software can detect resistivity value and depth model based on the resistivity apparent curve trend. Afterward, the results are processed using PROGRESS v.3 to complete the inverse modeling (Fig. 3). Inverse modeling is done iteratively to get the minimum RMS error. Finally, the best results were obtained at a minimum RMS error of 10%.

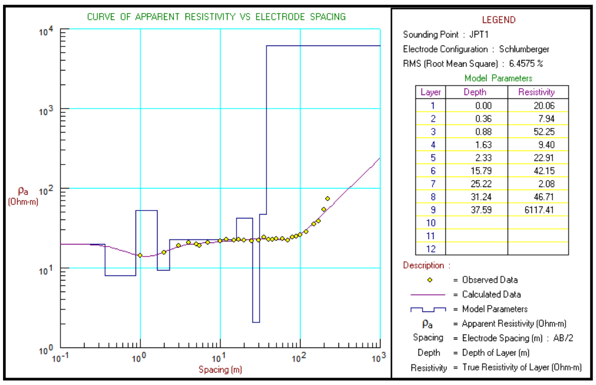


Figure 3. Inverse modelling to calculate true resistivity in JPT-03 using progress software (see Fig. 1 for the location of JPT-03).

GEOLOGY AND HYDROGEOLOGY

The research area is located in a complex geological setting created by the collision process of three plates, namely the Australian Plate moving northward, the Pacific Plate moving westward, and the Eurasian Plate moving south-southeastward (Hamilton, 1979; Hutchitson, 1989). This inevitable condition accounts for South Sulawesi to have hills morphology extended from north to the south of the province. Based on the lithology characteristics of groundwater aquifers in the research area is included in young volcanic aquifer in which the water flows through pore space and fractures. This type of aquifer has moderate productivity characterized by fair aquifer distribution having deep water table and debit commonly less than 5 litre/sec (Pratiknyo, 2008).

The hydrogeological setting of Sulawesi Island consists of several groundwater basins. One of them is Bantaeng Basin to which the research area belong. This basin has approximately 300 km^2 area with unconfined groundwater infiltration rate of 600 million m^3/year and confined groundwater infiltration rate of 5 million m^3/year (Pratiknyo, 2008). The lithology of the area is a young volcanic formation consisting of claystone, siltstone, tuffaceous sandstone and volcanic breccia proven by the outcrop found near research area (Fig. 4a). Tuffaceous sandstones are likely to be the most potential aquifer in this area.

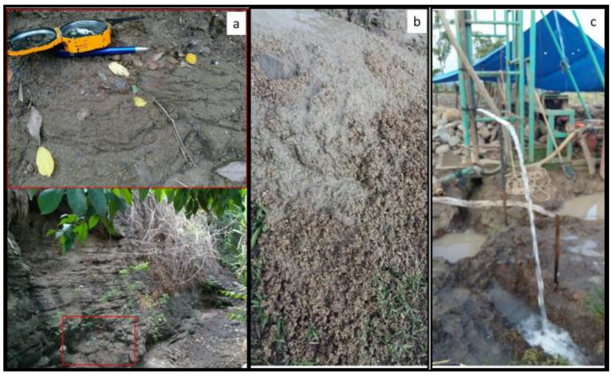
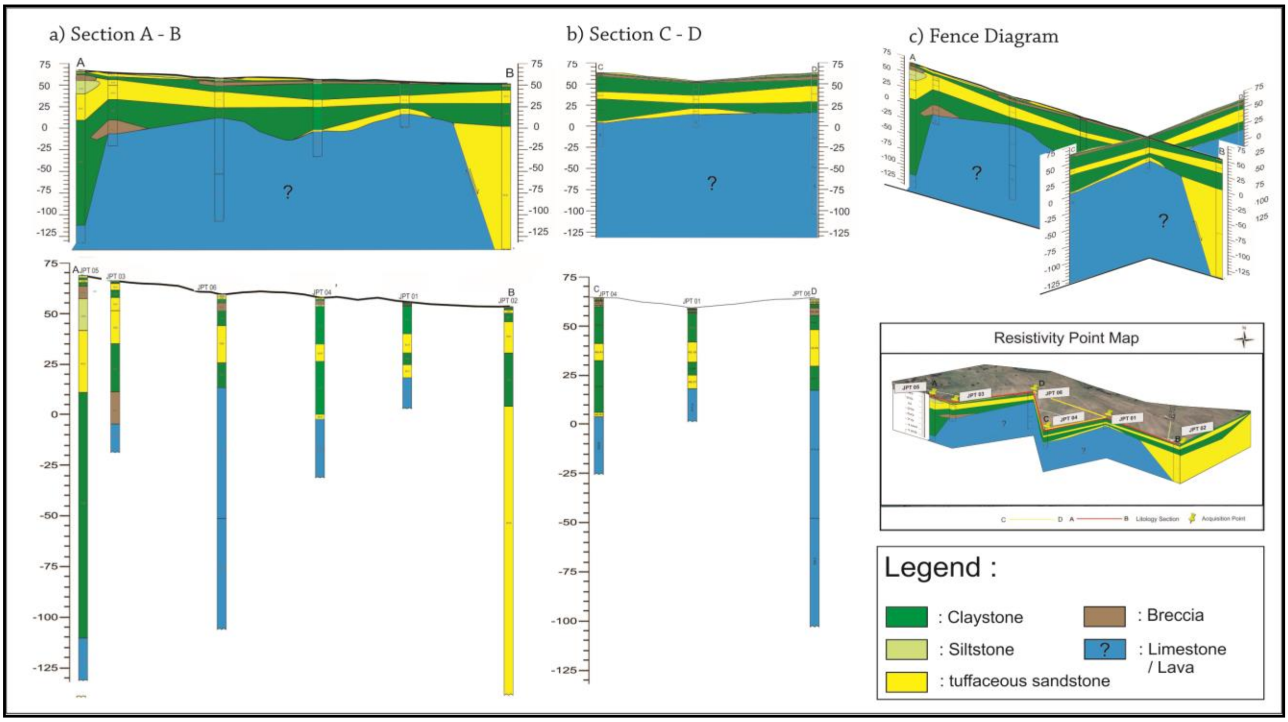


Figure 4. Tuffaceous sandstone in the outcrop (a) and from well cutting (b) as aquifer potential in the area. The sandstone is proven as water aquifer in the JPT-02 well (c).

RESULT

Based on the true resistivity values, the hydrogeological components of the research area are classified into the following groups (see Fig. 5):

1. Resistivity values of claystone layers range from 0.87 to 10.63 ohm-meter (dark green color in Fig. 5). This layer is highly conductive because it is made of liquid or semi-liquid mixture of unconsolidated materials and water.
2. Resistivity values of siltstone layers range between 12.74 and 22.91 ohm-meter (light green color in Fig. 5). This layer is interpreted as an impermeable rock.
3. Resistivity values of tuffaceous sandstone layers ranges between 18.83 and 58.25 ohm-meter (yellow color in Fig. 5). This layer is likely to be saturated by water.
4. Resistivity values of breccia layers ranges between 62.46 and 159.5 ohm-meter (brown color in Fig. 5).
5. Resistivity values of limestone/lava layer with ranges 414 to 6117 ohm-meter (blue color in Fig.



5). This layer could be either limestone or lava considering its resistivity value.

Figure 5. Geological profile of the area (top) and lithological logs acquired from resistivity results (bottom). Each horizontal profile from all acquisition points is correlated in to two sections with north to south (a) and west to east direction (b). Both sections are combined into a single fence diagram (c).

Figure 5a shows that the depth of limestone and claystone in the southwest part (JTP-01, JTP-04, JTP-06, JTP-03, and JTP-05) is deeper than it is in southeast part of the area (JTP-02). This suggests that the interpreted aquifer layer is in abundant tuffaceous sandstones found only at JTP-2 site (Fig. 4b). The potential of tuffaceous sandstones as aquifers is due to its characteristics which have good permeability and porosity to be able to accommodate and let the water through. In contrast, the other locations only have a thin tuffaceous sandstone layer so that other locations have unfavorable lithology as an aquifer. The correlation results also show that there is a thick layer of sandstone on JTP-02 at a depth of 50 meters below the surface marked with yellow. This layer is highly likely to be a groundwater aquifer in the JPT-02 well (Fig. 4c).

ACKNOWLEDGEMENTS

The authors thank to the Ministry of Villages, Acceleration of Development in Underdeveloped Regions and Transmigration of Republic of Indonesia, The Directorate of Facilities and Infrastructure Improvement. The authors also thank to Mr. Saudi from the Ministry of Villages, Acceleration of Development in Underdeveloped Regions and Transmigration of Republic of Indonesia, Mr. Khusnul from the local government of South Sulawesi, and Mr. R. Antho from the contractor for helping in acquiring the data.

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