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A PRELIMINARY STUDY ON AQUIFER IDENTIFICATION BASED ON GEO-ELECTRICAL DATA IN BANDA ACEH, INDONESIA

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Abstract. The aquifers exploration has been conducted at the western part of Banda Aceh, Indonesia. This research aims to explore the aquifer layer beneath the surface and to obtain the cross-section model of the aquifer. The Vertical Electrical Sounding (VES) method was applied to investigate the aquifer layer. The VES method worked as the current penetrated into the ground using of two electrodes and the potential response due to its current being measured by another two electrodes. Ten grid points of VES has performed in western part of Krueng Aceh of Banda Aceh using the ARES (Automatic Resistivity Meter). The Res1Dinv and curve matching computer software used in VES data processing and analysis. The result shows the resistivity value of aquifer in Banda Aceh city at the range of 1 – 12 Ωm for freshwater, and 0.1 – 0.6 for brackish water layer. The first aquifer (water table) found at a depth of 0.5 to 2 meters beneath the surface. The 2-meters water table mostly located near the coastal zone or downstream zone of Krueng Aceh basin and shallow depth of 0.5 meters on the upstream. More than one aquifer layers were found beneath the surface, they were separated by aquitard layer consisting of silt to clay layers.

Keywords: Aquifer, Geo-electric, Banda Aceh, VES, ARES

I INTRODUCTION

Banda Aceh is a capital city of Aceh province located on the tip of Sumatra Island. According to Central Bureau of Statistics (BPS) [1], Banda Aceh has an area of 61.36 km² and inhabited by 259,913 people. The number of the population in Banda Aceh increases each year leading to the increasing need of water consumption and usage. Thus, the exploration for water resources is compulsory as the population and the city are growing. The use of technology, especially geophysical methods, to investigate groundwater is necessary to reduce the cost and time, to estimate the site and the depth of bore hole, or well. The Geo-electric method can map and interpret subsurface conditions based on the electrical properties of the soil [2]. Implementing the Geo-electric to investigate the groundwater in Aceh province has been conducted by Rusydy, et al. [3]; Kurnia, Mulia, & Marwan [4]; Idris, et al. [5]. First resistivity method in Banda Aceh performed by Culshaw et al. [6] in developing the engineering geology map of Banda Aceh in 1979. This research aims to determine a distribution of groundwater layer (aquifer) beneath the surface around the western part of Banda Aceh and to obtain the cross section model of the aquifer. This research is expected to provide the hydrogeological information concerning aquifer layers in Banda Aceh to the local government. According to Benneth et al. [7], Banda Aceh is situated on alluvium formation consisting of gravel, sand, silt, and clay. The alluvium formation has a high potential of water resources and it is located beneath the surface. Culshaw et al. [6] noted that the alluvium formed along Krueng (river) Aceh deposit, and it is called as Krueng Aceh basin. The basin itself is infilled with recent alluvial and marine sediment up to a depth of more than

179 m. It is believed that this deeper basin will produce a high capacity of groundwater and its layer (aquifer) will form several layers in the sub-surface. The Jurassic to Cretaceous limestone formed in the southwest to the south of the basin, and in the east north to east found the quaternary volcanic rock. Barber & Crow [8] and Rusydy et al. [9] recognize this southwest to the south limestone as an oceanic accretion rock which has highly joints, trust fault and is part of Woyla group. Culshaw et al. [6] made the description of the quaternary deposit in Krueng Aceh basin; they divided the basin into three areas. In the north and east of Darussalam, a series of Sand-bars formed the sub-parallel to the coast. This unit consists of fine to medium grain size sand and sometimes of silty sand. The composition of these Sand-bars is similar to the modern beach sand and the sand along the channel Krueng Aceh. Grey to brownish silty clay is deposited between this sand-bars unit. To the west of Darussalam, a modern sandy beach ridge is formed and followed by the lagoon either at the right of left side of Krueng Aceh. The sand body extensively come from coastal zone to inland and has no pattern. In the east of Krueng Aceh, the number of terraces is formed by erosion. These terraces consist of sands, sandy silts, and clays with sporadic sandy gravels and gravelly sands. Near the Limestone in the southwest of Banda Aceh or west of Krueng Aceh, the sand and silty sand unit with limestone fragment interlock with finer deposit is found. This western part of Krueng Aceh is the study area of this research. Tohari, et al. [10] found the alternating alluvium layers between sand to silty sand with silty clay to clay at a depth of approximately 20 m from the surface in our study area. Ploethner and Siemon [11] in their report noted that the bore hole data in Cot Paya village which is close to the coastline up to a depth of 206 m and they still found the alluvium deposit from Pleistocene to Holocene. Moving landward to the upstream; they found the alluvium deposit consisting of sandy clays and claying sand up to a depth of 70 m. The sand layer formed in the Krueng Aceh basin has high porosity, permeability, and therefore it is highly potential to be the aquifer layer. However, this hypothesis must be proven using the geo-electrical data (Figure 1).

II MATERIALS AND METHODS

Geo-electrical method is a geophysics method to investigate the sub-surface conditions based on the electrical properties of the rock. Geo-electrical method works by passing an electrical current along many different paths through the earth materials. The electrical current, the movement of charged particles, can take place in three different ways. In the first mode of conduction, ohmic conduction, the electron flow through the crystalline structure of some material. The electric current is also conducted by dissolved ions in groundwater [2, 12]. 1D Resistivity imaging method was one of the geo-electricmethods to determine the subsurface condition based on resistivity property of the earth materials [2]. Ernstson and Kirsch [13] recognized this method as Vertical (1D) Electrical Sounding (VES), and it is applied to study the horizontal or approximately horizontally layered earth. This method was carried out using a system of four electrodes placed on the ground surface.

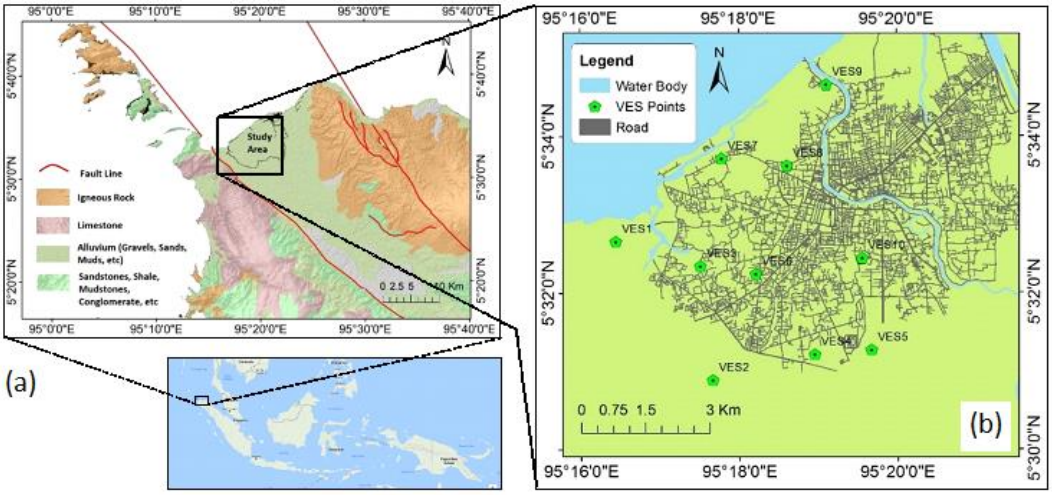

Figure 1. (a) The Geology Map around Banda Aceh City, modified from Bennet, et al. [7], and (b) the location of VES points.

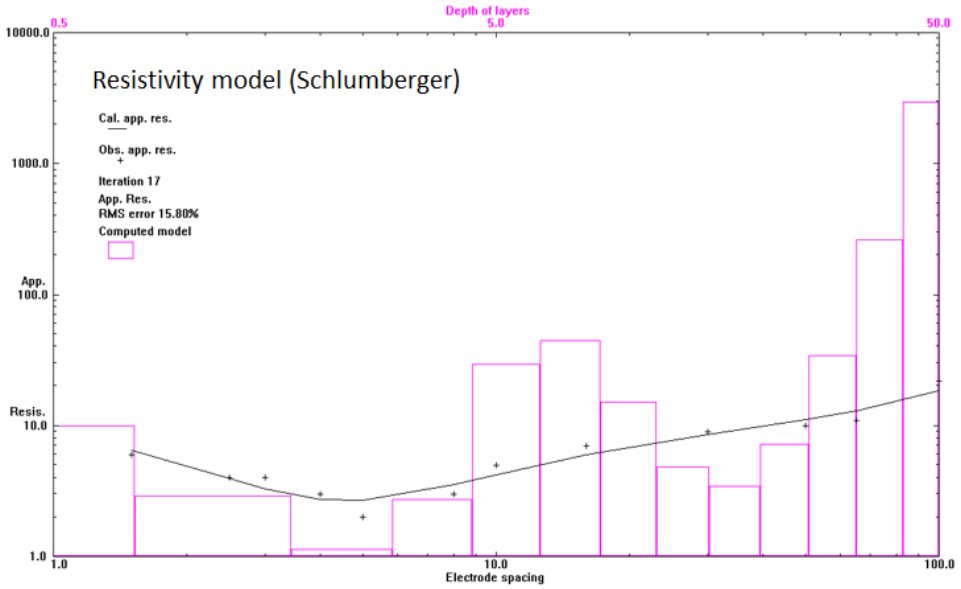

Figure 2. The example result of VES05 after processing using Res1Dinv

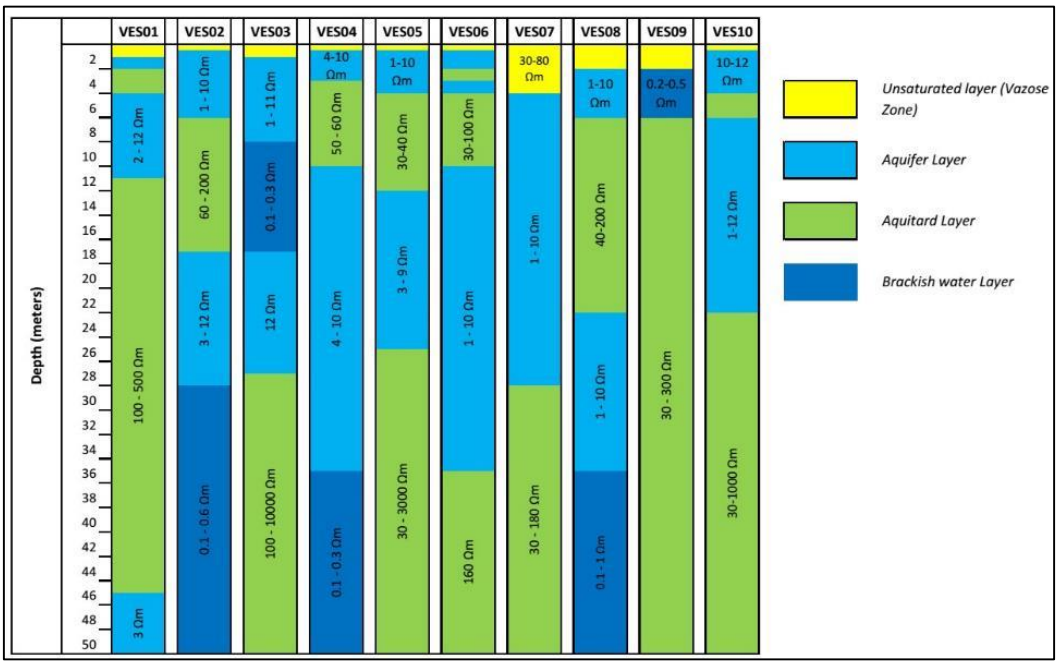

Figure 3. The result of VES survey in Banda Aceh city, see the map to locate the position.

Two current electrodes were used to pass the current into the subsurface, and it will cause potential difference values (ΔV) measured with other two electrodes. This configuration will allow us to calculate the apparent resistivity value (ρa) using Ohm's law;

$$R = \frac{\Delta V}{I} \quad [1]$$

$$\rho_a = K\,R \quad [2]$$

Where K is the geometrical factor depending on the type of electrode array and R is the resistance of the ground from Ohm's law in the Eq [1]. The apparent resistivity (ρ_a) is related to the true sub-surface resistivity [2, 12]. In general, linear electrode configuration are used for measuring the resistivity. The configuration are Wenner, Schlumberger, and Dipole-dipole. Ernstson and Kirsch [13] noted that VES mostly use the symmetrical Schlumberger configuration where the current electrodes A B move outward and the voltage electrodes M N are closely spaced and fixed to the center of the array. Ten grid points of VES has performed in the western part of Krueng Aceh of Banda Aceh. The ARES (Automatic Resistivity Meter) was used to

measure the resistivity data beneath the surface. Furthermore, the Res1Dinv and curve matching computer software was used in VES data processing and analysis.

III RESULTS AND DISCUSSION

Ten points of VES have varied length of the line in AB, and it will yield different depth. Point VES02, VES03, VES04, VES09 and VES10 have current electrodes AB of 100 meters. For point VES05, and VES08, AB is 125 m, and 160 m for points VES01 and VES07. The shortest A B length is 80 m for point VES06. The varied AB length in the field depends on the availability of the open space at specific points. VES model from computerizing processing would show some ambiguity in the result. To void this, we refer to the actual sub-surface model of Banda Aceh developed by Ploethner & Siemon [11] and Tohari, et al. [10] from the bore hole and Cone Penetrating Test (CPT) data of VES01, VES02, and VES05 administratively located outside the city, but close to the boundary of Banda Aceh. The VES01 point is nearby the coastal area and hill site of the limestone.

The VES01 data processing shows that the aquifer layer has 2 to 12 Ωm, its sequence is found at a depth of 1 to 2 m, 4 to 11 m, and 45 to 50 m. The second and third aquifers are confined aquifers because they are separated by impermeability layer of aquitard layer. The aquifer at this location is predicted to be formed by sand to the silty sand unit. This interpretation made as it is not far away from VES01. Tohari et al., [10] found sand to silty sand layer at a depth of 0 to 5 m and 9 to 12 m. Beneath the second aquifer, the high resistivity layer found from 13 to 45 m, and it has 100 to 500 Ωm. This high resistivity layer is aquitard, and it is interpreted as claying silt to silty clay, and it is line with Tohari et al. [10] result. An aquitard is a geological formation which transmits the water at slower rates compared to an aquifer. The aquitard as a less-permeable beds is formed in a stratigraphic sequence. This aquitard formed in an interlayered sand-silt sequence and the sand may be considered an aquifer. On the other hand, when the silt formation aquitard clays, shale, and silty clays are the stratigraphic units, the sand can be considered as aquitards [14].

At VES02, three layers of aquifer is found at different depth. The first aquifer is found near the surface at a depth of 0.5 to 6 m. The second aquifer is located at a depth of 17 to 28 m. First and second aquifers at VES02 are separated by aquitard at a depth of 6 to 17 m. This aquitard layer is formed by interlayered silty sand to silty clay sequence. Below the second aquifer, a very low resistivity layer is found at a depth of 28 to 50 m which is interpreted as brackish aquifer layer. Brackish water has resistivity value in the range of 0.3 to 1 Ωm [2, 12]. This brackish aquifer layer likewise found in VES03 at a depth of 8 to 17 m. The VES03 is adjacent to the coastal line, approximately 1.7 km and 50 m to the lagoon. Above this brackish aquifer, the fresh water is found at a depth of 1 to 8 m and has 1 to 10 Ωm, below the brackish aquifer, another fresh water is found in VES03.

At VES04, the first aquifer found at a depth of 0.5 to 3 m and the second aquifer at a depth of 10 to 35 m. Aquitard layer separate first and second aquifer. Beneath the second aquifer at VES04, the brackish water found at a depth of 35 to 50 m. At VES05, two aquifer layer located at a depth of 0.5 to 4 m and 12 to 25 m. These aquifers layer is separated by aquitard formed by silt to clay layer. The interlayered aquifer and aquitard also are found at point VES06. The aquifer layer formed by sand layer and the aquitard layer consist of silt to clay unit.

VES07 is located near the coastline and VES shows this area is not affected by the seawater intrusion. The water table in this area is quite low yet it is very thick due to being far from the downstream. The aquifer is found at a depth of 4 to 28 m and beneath this layer, the aquitard layer is located from 28 to more than 50 m. The aquifer layer is probably formed by the sand unit. At VES07, the aquifer is discovered from the depth of 2 to 6 m. The second aquifer is found at the depth 22 to 50 m, however, this second aquifer contains fresh and brackish water. The similar depth of brackish water is also found at VES04 and VES02. At VES09, the brackish water layer directly is found at a depth of 2 to 6 m. The fresh water is not found at VES09 as this area is nearby the coastal zone and downstream of Krueng Aceh. VES10 has similar characteristic to VES05 which has a shallow water table. At VES10, the first aquifer is found from 0.5 to 4 m. The aquitard layer located at a depth of 4 to 6 m, and it interpreted as silt to clay unit. This interpretation based on borehole data obtained from a previous study [10] nearest to VES10. Beneath this aquitard layer, the confined aquifer is found from 6 to 22 m and another aquitard is found below confined aquifer up to 50 m.

CONCLUSIONS

Ten VES data reveal the several layers of the aquifers beneath the western part of Krueng Aceh of Banda Aceh. The single aquifer layer is

only found at VES07 and VES09, and the rest are the interbedding layers between the aquifer and aquitard up to 50 m. The resistivity value aquifer beneath Banda Aceh city in the range of 1 – 12 Ωm for freshwater and 0.1 – 0.6 for brackish water layer. The first aquifer (water table) is found at a depth of 0.5 to 2 m beneath the surface. The 2-m water table mostly located near to the coastal zone or downstream zone of Krueng Aceh basin. The shallow aquifer of 0.5-m is situated mainly at VES02, VES04, VES05, and VES10 which is far from the coastal area and at the upstream zone. The thick aquifer layers are found at the VES04, VES05, VES06, and VES07. These points have lineament and it is perpendicular to the coastline. Several aquifer layers are found in the subsurface and those layers are separated by aquitard layer consisting of silt to clay layer.

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