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Geophysical and Hydrogeological Study for Evaluating Seawater Intrusion in Coastal Aquifers of Amphoe Cha-am, Changwat Phetchaburi

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Abstract

The study area is a famous tourist coastal area, located in Amphoe Cha-am, Changwat Phetchaburi, where contains densely populated area. The need of a large amount of fresh water thus tends to be increased as well as intensive extraction of groundwater from coastal aquifers has decreased freshwater outflow to the sea and leads to local groundwater depression. Seawater intrusion is one of the rising problems in this area due to seawater movement inland and rising toward fresh water well. In this study, an integrated geophysical and hydrogeological study was carried out to evaluate seawater intrusion in coastal aquifers. The 22 dataset of vertical electrical sounding method (VES), is useful to identify variations in electrical characteristics of coastal aquifers. Hydrogeological characteristics were generated from drilling data, electric log data, measured static water levels, and well screen depths. By integrating both investigations, we found that seawater intrusion mainly occurs in Qcl aquifer at a depth of 30-50 meters and laterally intrudes about 7 kilometers inland. Furthermore resistivity values ranging between 0-10 Ωm, represents Qcl getting highly influenced by seawater intrusion, while resistivity values are in the range of 10-15 Ωm in Gr aquifer, suggesting that is partially influenced by seawater intrusion.

Keywords: Coastal aquifer, Hydrogeological characteristics Phetchaburi, Seawater intrusion, Vertical electrical sounding method

1. INTRODUCTION

Many coastal areas have integrity of food and important economic activities such as urban development, trade and touristic activities. These are factors attracting people to settle up, as a result, the need of fresh water demand increases. Groundwater resource is the alternative water source since it has high quality, hardly seasonal effects and huge available quantities) (Essink, 2001). In the coastal aquifer, seawater is lied under fresh water since fresh water has less dense than seawater as well as, zone of contact between fresh water and seawater is brackish water (Bear, 1999). Although fresh water lies over the top of heavier seawater and serves to push the seawater interface seaward, while pumping a large amount of fresh groundwater from coastal aquifers consequently, the pressure of fresh water is decreased, which in turn induces seawater intrudes landward into fresh water aquifers (Ramingwong, 2003). Seawater intrusion problem is one of the most important environmental issues that negatively affects groundwater resources significantly (Essink, 2001; Werner et al., 2013). Therefore, the study of seawater intrusion into coastal aquifers is needed to identify the zones affected by seawater intrusion to prevent problems or properly remediate such problems efficiently. The study area is located at Amphoe Cha-am, Changwat Phetchaburi because it has been considered as densely populated area and one of the famous tourist areas in Thailand recently. The groundwater resource may be a primary water resource in the near future and is consequently drawn out over the safe yield of coastal aquifers. Under this situation, the natural equilibrium of fresh water and seawater interface is directly changed, causing that the sea water laterally moves landward.

In this study, an integrated geophysical and hydrogeological study has been applied to investigate areas disturbed by seawater intrusion (Nowroozi et al., 1999; Sabet, 1975; Van Dam and Meulenkamp, 1967). Geophysical technique used the 1-D electrical resistivity surveys or vertical electrical sounding (VES) in view of the fact that the VES technique enable the large areas with less time-consuming and an economical cost, as compared with drilling exploration methods. However, geophysical survey data is not capable of identifying clearly lateral penetration of seawater in various lithologic units in a hydrogeological formation (Zohdy et al., 1974). Therefore, this research together used hydrogeological information (Konkul et al., 2014) to support geophysical data and interpret to evaluate seawater intrusion in coastal aquifers.

1. MATERIAL AND METHODS

1.1 The study area

The study area is located in Amphoe Cha-am, Changwat Phetchaburi, which is part of the central part of Thailand (see Figure1) . The area lies between latitudes 12°45'0" N and 12°41'40" N and longitudes 99°52'30" E and 99°58'20' E. The study area covers about 54.3 square kilometers consisting of 2 Tumbons, which are Sam-Pra-Ya and Cha-am.

This area can be classified the topography into 2 major landforms. The first landform is a plain interleaved mountain that covers area 20 % of the total area. The second landform is a low-plain or coastal plain that covers area 80 % of the total area. The plain interleaved mountain landform is located on the western of the area, which has slope more than 40 %. The mountain range is lined along the coastal line in north-south direction. The eastern side of the area is a low-plain or coastal plain, connected to the Gulf of Thailand. The slope of the area is less than 2 % and an average height is ranged from 5 to 20 meters (msl) . The coastal characteristic is a beach sand and estuary caused by deposition of river sediments. In the central of the area found alluvial plain at the narrow zone between mountains. The average height of this area ranges from 30 to 60 meters (msl).

Land use in this study area could be separated into 4 types. The first is agriculture areas, which are the most common in this area. It was dispersed in the middle part of study area, which is mostly the low lying land. The second is forest area. There are mostly located in the high plateau and mountain, in the western area and some scattered in the middle part. The third is facility areas that are scattered along the coastal line, mainly located in the western parts of the area. The last is water body that is very small size compared to the whole area.

Amphoe Cha-am has three seasons, summer (mid-February to mid-May), rainy (mid-May to mid-October), winter (mid-October to mid-February). The climate of Amphoe Cha-am generally is under the influence of two monsoons wind, that circulation regularly as the season. The first is the northeast monsoon that blows from northeast in the winter. The second is southwest monsoon that blows regularly in the rainy season and blows across the Indian Ocean. Consequently, Thailand has a lot of rain. Nevertheless, Amphoe Cha-am is behind the Tanaosri Mountain ridge, a rain shadow that is the reason why it is less rainfall during the rainy season and mostly rain is occurred during October to November.

1.2 Geophysical and hydrogeological investigation

Geophysical and hydrogeological investigations were carried out in the study area. The geophysical investigation was collected in dry season since seawater intrusion may occur evidently.

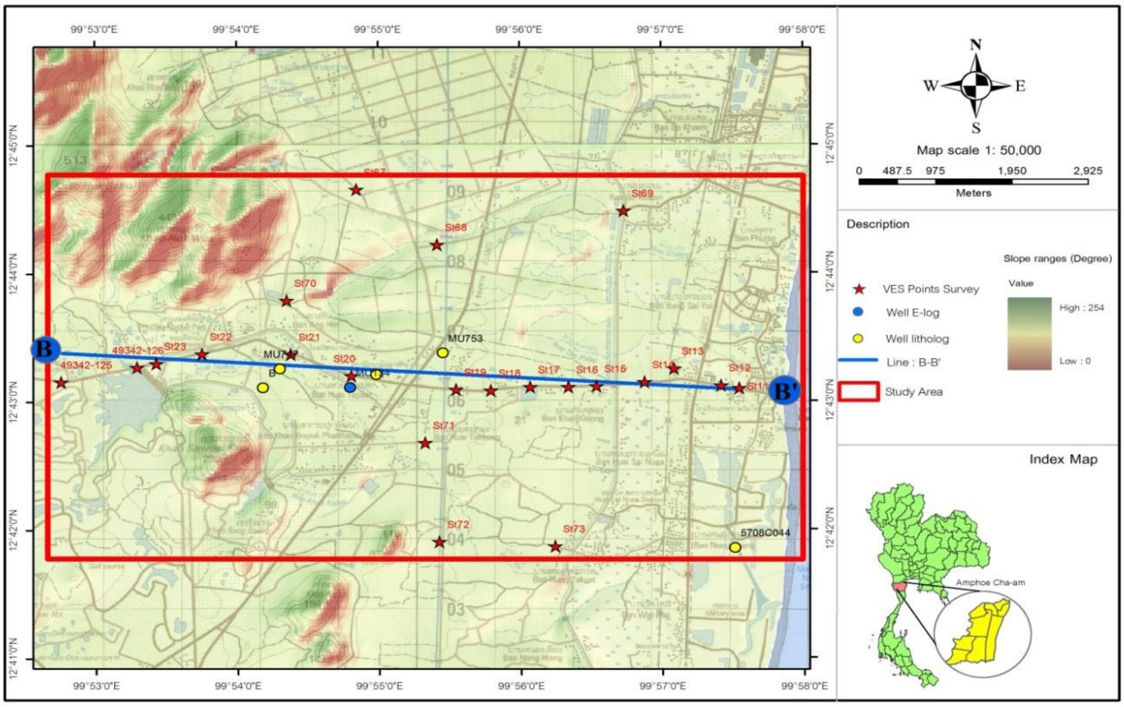

Figure 1 Showing topographic map of the study area (adapted from topographic maps edition No.1-RTSD L7018 series, sheet number 4934 II).

One-dimensional resistivity survey known as Vertical Electrical Sounding (VES), was applied in this study. The results of VES survey is the resistivity values of soil and rocks layers. The principle of VES is to release electrical current into the ground by means of metal electrodes to detect the electrical conductivity (EC) of subsurface formation, which is depends primarily on three factors: porosity, connectivity of pore and the specific conductivity (Telford et al., 1990) . Because the difference between the ECs of freshwater and seawater is significant, electrical resistivity surveys are well suited for studying the relationship between the two in coastal aquifers (Sherif et al., 2006). The 22 VES points were collected by using the Schlumberger configuration (see Figure 2) and Syscal R1 Plus model electric resistivity meter. The current electrodes (C_1 and C_2) spacing were measured in meters and varied from 1 to 200 meters and potential electrodes (P_1 and P_2) varied from 0.25 to 20 meters. The selected current electrodes spacing are: 1, 1.5, 2, 3, 5, 7, 10, 15, 20, 25, 30, 35, 40, 45, 50, 60, 70, 80, 90, 100, 110, 125, 135, 150, 160, 175, 185 and 200 meters. The locations of VES surveys were shown in Figure1. The resistivity data derived from field was interpreted by using IPI2WIN software version 3.1.2c that developed by Moscow State University (Bobachev, 2003). By adding the data, then the software was calculated and calibrated graph with the most possibility. The interpretation from the program displays as a layer according to the resistivity values and the one can adjust their values accordingly.

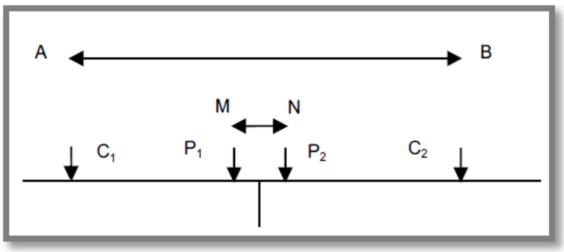

Figure 2 Schlumberger configuration

Hydrogeological characteristics represent geological features associated with properties of rock that is a groundwater reservoir, including the occurrence, distribution and flow of groundwater. Typically, hydrogeology characteristics are classified into two main types: unconsolidated rocks and consolidated rocks, and then classified into sub-hydrogeologic units, depending on the hydrogeological properties in terms of storage and discharge properties. After processing all geophysical survey points completely, the hydrogeological cross-section was constructed with the help of lithologic log data, electric log data**,** measured static water levels, and well screen depths.

2. RESULTS AND DISCUSSION

2.1 Vertical Electrical Sounding results

Results of the VES survey were displayed on the log-log graph between electrode spacing and apparent resistivity values that can be used to identify soil and rock layers. Shape and slope of VES data on graph represents changes among layers having different resistivity values (Telford et al. 1990). All 22 VES data showed the H type curve (see Figure 3) (Telford et al. 1990). This implied that there were three layers in the subsurface that consist of resistivity: $\rho_1 > \rho_2 < \rho_3$ (ρ_1= resistivity of upper layer, ρ_2= resistivity of intermediate layer and ρ_3= resistivity of bottom layer) (Song et al., 2006) and consistent with characteristics of geology and hydrogeology of study area. The top layer represents the unsaturated sediment, the middle layer was saturated sediments and the bottom layer is as a base rock.

There were 16 VES data used to create a pseudo cross-sections B-B’, which was perpendicular to the coastal line, starting from the western to eastern areas (see Figure 4). Total distance of this line is approx. 8,450 meters. Sixteen VES points are follows: St11, St12, St13, St14, St15, St16, St17, St18, St19, St71, St20, St21, St22, St23, 42-126 and 42-125 (see Figure 3). From Figure 4, it was found that the surface layer (0-10 meters) has resistivity anomalies between 10 to 400 Ωm, representing unsaturated zone of aquifer. The next layer showed resistivity values ranged from 2 to 20 Ωm. It could be interpreted as sediment layer saturated with groundwater. Near the coastal line, there is low resistivity zone (0-10 Ωm) in Qfd that extends approx. 2 kilometers inland. It seems to represent the influences of seawater intrusion. Low resistivity values (0-10 Ωm) is consistent with a study of Nowroozi et al. (1999), Cimino (2008) and Kouzana et al. (2010). They found that the area where low resistivity in range 0 to 10 Ωm is influenced by seawater intrusion. For the western side of profile at the depth of 20-200 meters, it showed the zone of resistivity ranging from 60 to 250 Ωm, representing bedrock layer.

The geological cross-section (see Figure 5), of west-east direction, was established by combining the data from the VES data with lithologic log data and electric log data of boreholes in the area (see Figure 6). It showed that the maximum depth of aquifer is approx. 200 meters. The cross-section clearly showed the boundaries of each aquifer. The top layer is Qfd aquifer consisting of sand (well sorted and high sphere), from 0 to 20 meters thick. The next layer is Qcl aquifer, consisting of clayey gravel (poorly sorted and angular to sub-angular) and interbedded with sand in some areas with an average thickness of 50 to 60 meters, but it may be up to 100 meters in the area near the coastal line. The bottom layer is Granite (Gr) aquifer that represents the base rock in this area, and plays the barrier role against the seawater intrusion.

2.2 Hydrogeological characteristics

The study area is underlain with both unconsolidated and consolidated aquifers. Unconsolidated aquifers in study area are quaternary sediments, that can be classified by the depositional environment into 3 aquifers as follows: 1) Quaternary Beach-Sand Deposits (Qbs), 2) Quaternary Floodplain Deposits (Qfd) and 3) Quaternary Colluvial Deposits (Qcl). In Amphoe Cha-am, Qbs consisting of

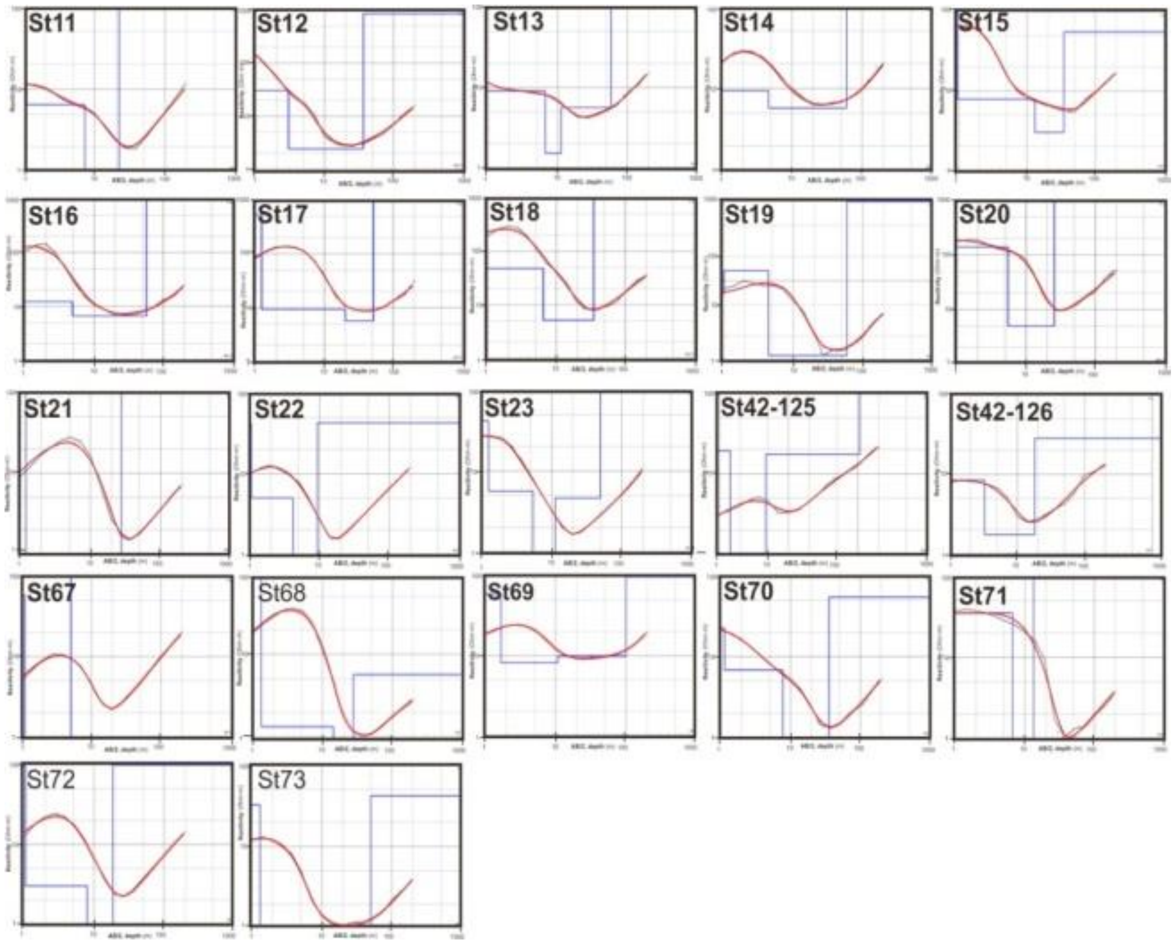

Figure 3 Inversion results from VES with the Schlumberger configuration of 22 VES points

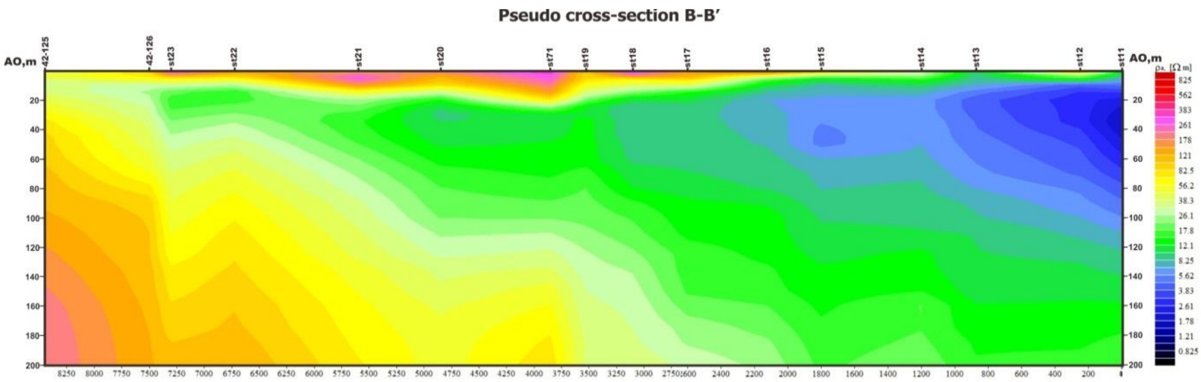

Figure 4 Pseudo cross-section lines B-B’

common sediments in the coastal plains area, is distributed along the coastal areas. The sediments are well sorted and rounded. The average depth of aquifer is 5 to 8 meters with a groundwater level of 1 to 2 meters (msl). Qfd is sediments deposited along meandering belts and floodplains area. In study area, Qfd mostly is dispersed over a wide area in the upper part between Qbs in the eastern part and Gr in the western part and mainly covers in the southern area. This aquifer is deposits of well-sorted and well-rounded sand and gravel of channel, river and flood basin deposits. The average depth of Qfd ranges from 25 to 45 meters with groundwater

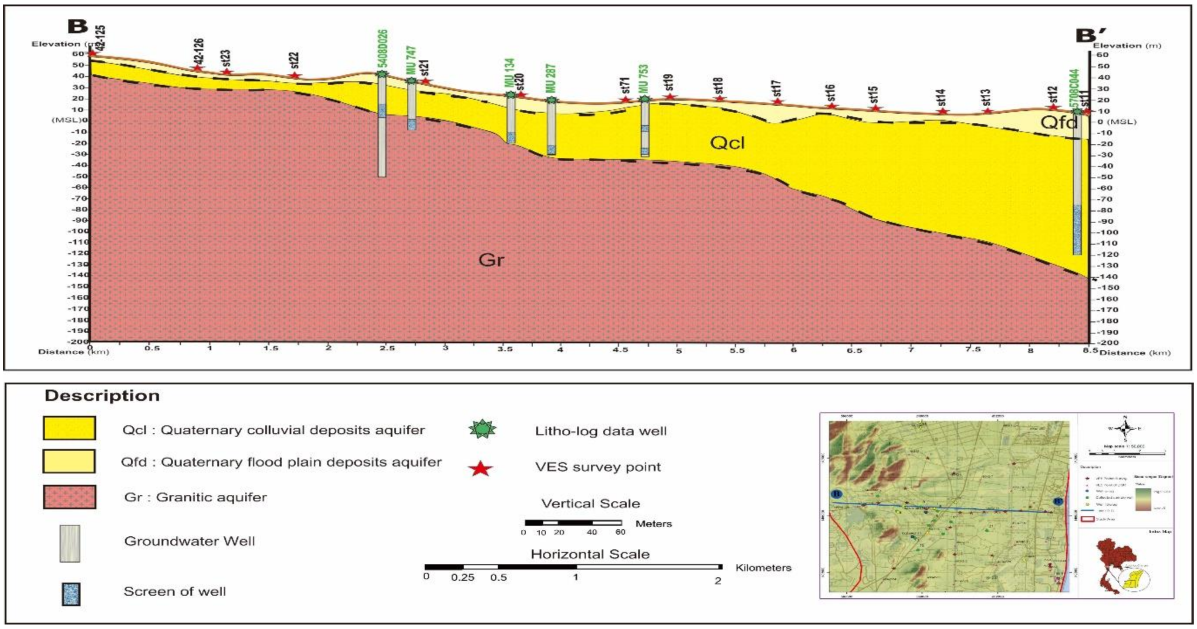

Figure 5 Geological cross-section lines B-B'

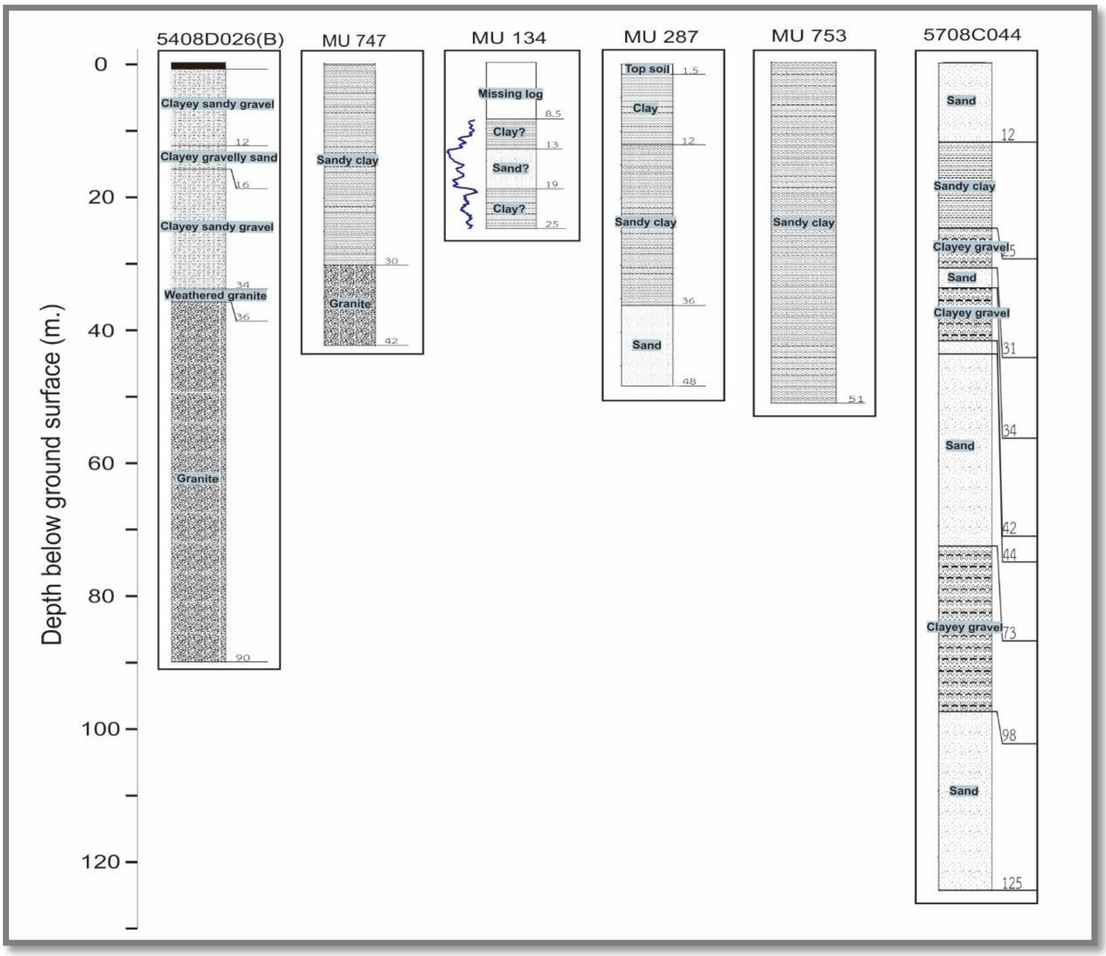

Figure 6 Showing lithologic log data, electric log data of drilling well and simplified geologic section in line B-B'

level of 3 to 8 meters (msl). In study area, Qcl is found near the foothill of the granite mountain in the western area, consisting of gravel, sand, quartzite fragments, granite fragments and clay. They are poorly sorted, angular to sub-angular because of weathering of source rock and rapidly deposition. The average depth of Qcl ranged from 30 to 50 meters (msl). Consolidated aquifer in the study area is Cretaceous Granite aquifers (Gr). Gr aquifer has been dispersed along the large mountain ranges in the western part of this area. Groundwater has accumulated in the fracture, joint zone, fault and weathered zone with an average depth of 50 to 150 meters and groundwater level range from 6 to 9 meters (msl).

3. CONCLUSIONS

Assessment of seawater intrusion into coastal aquifer in this research used 22 VES survey. There were interpreted and shown as a pseudo cross-section. There were in good agreement with those obtained from both lithologic and electric log data in the study area. The results found that seawater dominantly intrudes to Qcl aquifer about 7 kilometers inland Qcl aquifer is highly influenced by seawater intrusion with resistivity values in the range of 0-10 Ωm while weathering Gr aquifer underneath Qcl aquifer at a depth of 50-60 meters is partially influenced by seawater intrusion with resistivity values in the range of 10-15 Ωm.

4. ACKNOWLEDGMENTS

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