TIME LAPSE RESISTIVITY INVESTIGATIONS ON SALINITY CHANGES AT EX-PROMONTORY LAND;

CAREY ISLAND, SELANGOR

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Time-Lapse Resistivity Investigations on Salinity Changes at ex-promontory land; Carey Island, Selangor

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ABSTRACT

A time-lapse resistivity measurement was used to study the effect of salinity to groundwater aquifers at ex-promontory land of Carey Island in Malaysia. Resistivity was measured through an ABEM Terrameter SAS 4000, combined with ES 10-64 electrode selector. The highest percentage of resistivity changes at the unconfined aquifer occurred after 1 hour maximum of high tide with value ranges from -80 to 450%. In contrast, the first semi confined aquifers, located 1.5km of shoreline showed the highest percentage occurred after 6 hours maximum of high tide with value ranges from -45 to 65%. It is expected that the percentage of resistivity changes will reduce for both aquifers system during wet season which will occur in October until February. This study will assist the modelers in obtaining the preliminary information of hydrogeology condition by using time-lapse resistivity measurements on at ex-promontory land.

Keywords: salinity changes, groundwater aquifers, ex-promontory land, time-lapse resistivity measurements

1. INTRODUCTION

Saltwater intrusion has been discussed in the literature as a source of contamination. Saltwater intrusion can pose serious problems to coastal areas with freshwater aquifer having marine-aquifer hydraulic interaction. In natural condition, saltwater intrusion happens when the low density of fresh groundwater interacts with the high density of saltwater. Other sources of saline contamination includes connate water of marine origin (Hing, 1994), saline water of canal and river which hydraulically interacts with aquifer (Mohamad et al., 2001). In these studies, hydro-geochemistry analyses from monitoring wells, and geophysical methods, were used. The best geophysical method assigned, particularly in salinity mapping, is geo-electrical method (Loke, 2000). Ever since the development of the interpretation technique, various researchers around the world have applied geo-electrical method in demarcating coastal-area hydrogeology condition. Awni (2006), Sherif (2006) and Adepelumi et al. (2009) used a 2-D geo-electric method in detecting subsurface freshwater and saline water at their study areas. All of the studies were conducted to detect and mapped the salinity of the area without involving any time and space domain for the salinity that changes dynamically through spatial and time with the tidal changes and seasonal condition. As the salinity changes are dynamic and happen every day in the groundwater system, therefore the time-lapse resistivity measurement method can be used to detect the changes in the subsurface resistivity by using the changes in the apparent resistivity measurements (Loke, 2000). These applications were used on the flow and contamination of groundwater in physical model testing (Barker and Moore, 1998), investigations of saltwater transport in glaciofluvial deposits during the de-icing salt (Leroux and Dahlin, 2006) and monitoring the impact of de-icing salt on roadside soils (Olofsson and Lundmark, 2009).

The same technique was implemented in this study at ex-promontory land; Carey island, which is located on the west coast of Peninsular Malaysia. The technique was used to identify the changes of salinity (through subsurface profiles) into the island coastal-area aquifer system, aided by time-lapse resistivity measurement and information related to the environmental history of the area.

2. MATERIALS AND METHODS

2.1 The Study Site

The study area is located on the west coast of Selangor, Peninsular Malaysia. Carey Island is separated from the Selangor coast by the Klang River on the north and the Langat River on the east. The rainfall exhibits some degree of variation in intensity, with most of the rain falling in the months of March to May and October to December. The period between Jun to August is relatively dry. There are two inter-monsoon periods, in April and October, which are generally characterized by variable winds and thunderstorms in the afternoon. The average monthly rainfall is about 180mm, while the annual precipitation is about 2100mm.

From the first version of the historical formation of the island, Carey Island was originally part of the mainland which was gradually disconnected due to piracy in the 19^{th} century. Second version mentioned that the island is promontory. It became an island when the Chinese broke through a little strip of land that separated the river from the straits and the rest of river is done by nature (Golden Hope Plantation Berhad, 2006). In 20^{th} century, E.V Carey transformed the island into rubber trees plantation. In order to irrigate the area, excavation of dykes, drainages, bunds and tidal gates were constructed to control the hydrology process. The history information has provided some idea on the hydrology and hydrogeology of the area after the land transformation of the island.

2.2 Geology and Hydrogeology

According to Suntharalingam and Teoh (1985), this area falls into marine sediments of Holocene age that occur over a large portion of the coastal area on the west side of Peninsular Malaysia and formally referred to as the Gula Formation. These sediments consist of grey clay and sand, minor gravel and absent trace of fragmented shells and peaty materials. There is no indicator of the outcrop exposed in the island accept the presence of granitic rock outcrop at Jugra Hills which is located at the river side of Langat river.

The land transformation of the island has changed the hydrological and hydrogeological condition of the area. The significant hydrological change was the cut-off of the surface runoff that flows from the upper catchment of Hulu Langat to this area. The island is relatively flat and there is no catchment area to store the freshwater from the precipitation. The nearest catchment area is Jugra Hill which is located outside of the study area. The drainage system used for the agricultural activity always been in saline condition due to unavailability of freshwater that can infiltrate through surface runoff or from the drainage of the upper stream. It is believed that the freshwater came from the base flow of the mainland or direct infiltration at unconfined aquifer from the island itself. Due to the shortage of freshwater source entering the island through the surface hydrology, it also affected the hydrogeological condition of the area.

In order to investigate the detail subsurface profiles of coastal alluvium, fourteen monitoring wells were constructed with the depth ranges from 40, 50 and 80m between Mac, and May 2009. The locations of the monitoring wells were allocated facing Straits of Malacca where it was assumed that the saltwater movement directly hit from the Strait of Malacca (Figure 1). Rotary-wash-boring method was used to drill the boreholes and soil samples were collected for visual examination and for laboratory test experiments to determine their physical parameters (BS 1377, 1990). After the wells have been constructed, the well development was done by using bailer and suction pump to remove trapped sediments. This will ensure a good acquisition data obtained for the groundwater quality and quantity.

2.3 Resistivity Survey

Electrical resistivity measurements were performed at the end of August which is the end of the dry season. The month of September is the transition month from dry to wet season. The geo-electric survey was conducted by the proposed device, ABEM Terrameter SAS 4000, combined with ES 10-64 electrode selector. Eight resistivity image profiles (Figure 1) were measured across the area. For each profile, 81 electrodes were strung and anchored into the ground surface at the site. The survey traverses were oriented N-S. The Wenner array was chosen for the resistivity traverses.

Loke (2000) indicated that the accurate results of time-lapse resistivity measurements can only be obtained if the apparent resistivity values themselves are accurately obtained. In order to obtain a good apparent resistivity data, there are few steps need to be taken to ensure a good ground contact and injection current. Among the steps were to hammer down electrodes more than 0.3m depth, maintaining the sufficient moisture of ground contact and using powered battery (60Ah) (Loke, 2000). In one day, five to six reading were taken in one hour period to observe the resistivity changes during changes of tidal condition. Groundwater samples were collected every hour to calibrate the geo-electric images with geochemistry data.

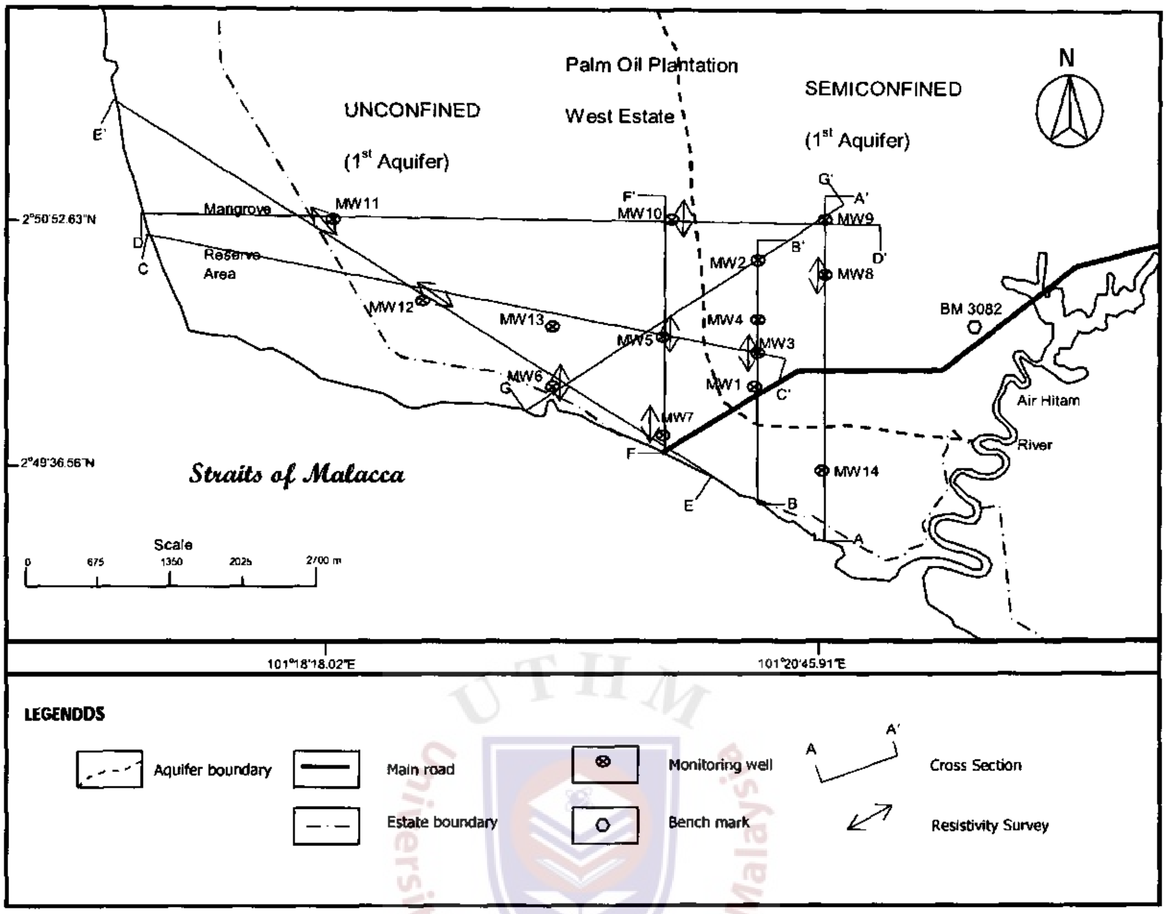


Figure 1: Location Of Monitoring Wells and Resistivity surveys

2.4 .Data Processing and Interpretation

Electrical resistivity data were processed and interpreted using the commercial software Res2Dinv, which allows full utilities of the software to analyze time-lapse resistivity using the dongle. Saltwater intrusion involved the movement of saltwater penetrating slowly into the groundwater aquifer. Intrusion of saltwater will be faster when there is pumping activities involved. The type of time-lapse inversion constraint used was the least-square smoothness constraint which showed the smooth changes of the image in the spatial and time domain. Sequential inversion method used because the section models display very large resistivity contrasts. This is shown by the lowest resistivity value ranges from 0.3 to 0.5 ohm.m compared to the highest resistivity value that ranges from 40 to 60 ohm.m. In the application of the sequential inversion, the full inversion of the first data set is first carried out for about 4 to 5 iterations.

The model for the first data set for the final iteration is then used as the reference model for the inversion of the later time data sets. The inversion and preceding of the later time data sets starts only after the completion of the inversion and preceding of the first data set. The first data set is used as the reference model for the second data set, while the model for the second data set is used as the reference model for the third data set, and similarly for the other data sets. The time-constraint weight value used was 3.0.

3. RESULTS AND DISCUSSIONS

Based on the borelog analysis, the lithology composed of Quaternary alluvium sediments more than 80m deep. The Quaternary alluvium sediments were composed of alternating layers of sand, silt and clay. No gravel was found during drilling and sampling. Figures 2 show a typical cross-section of the area studied that exhibit the complexity of the hydrogeology condition. Generally, two aquifers were found to be present in the Quaternary sediments at depth until 80m. For the distance up to 1.5km from the shorelines, the first aquifer can be categorized as an unconfined aquifer type. Meanwhile further up to 1.5km, the first aquifer type display the semi confined aquifer. The first unconfined aquifer composed of fine, light grey sand, with fragmented shells. The thicknesses of the first unconfined aquifer ranged from 10 to 40m. In the first semi confined aquifer, the thickness of the uppermost semi-impermeable layer varied from 27.00 to 31.50 m below ground surface which composed of light grey, marine silty clay. The depth of the aquifer can be encountered below ground level at the ranged between 25.00 and 33.00m. The thickness of these aquifers was unknown owing to borehole-depth limitation. Bedrock was not encountered at the area. Based on the boring conducted at the Kg. Sg. Judah, 30m away from MW8, granitic bedrock was encountered at 185m deep (Razip 2009, personal communication). There was no groundwater extraction for domestic or for economic use in this area.

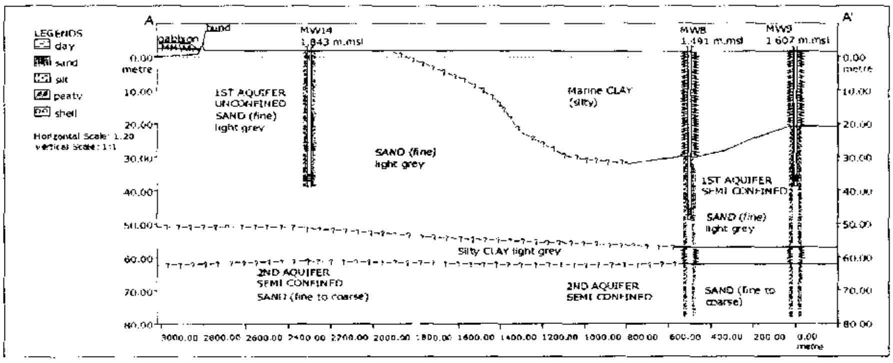
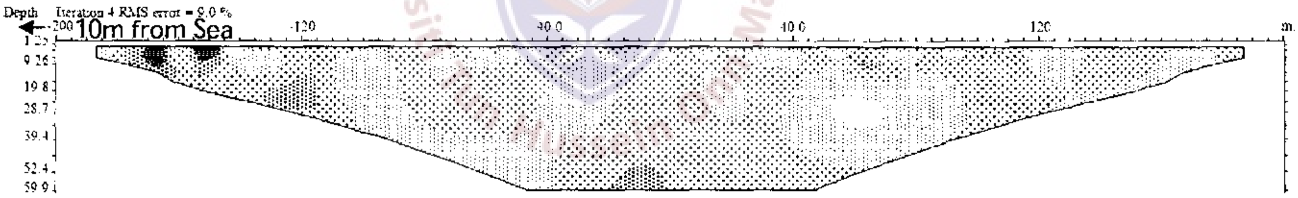


Figure 2: A typical cross-section of the area studied

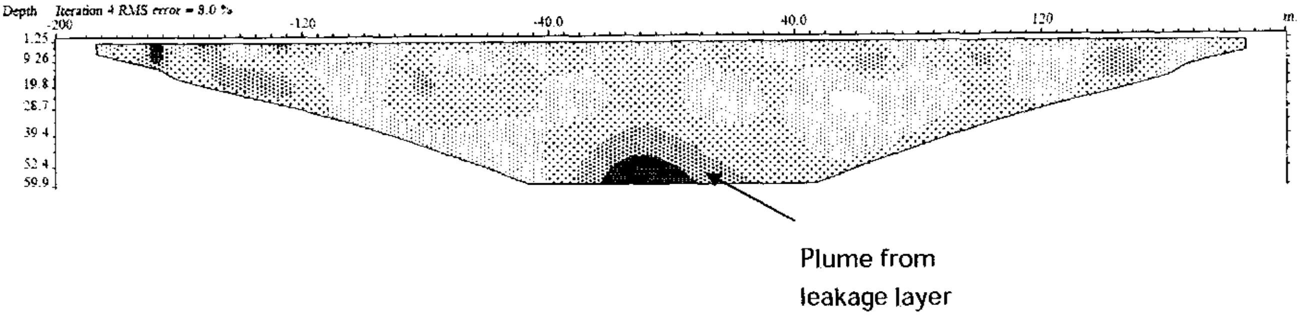
Figure 3 shows a series of difference sections using the data collected from MW7 (unconfined) at different times. The subsurface low resistivity zone reaches its maximum amplitude of about –80% to 600% after about 8 hours when the minimum low tide was achieved. After one hour measurement (two and half hours after minimum low tide level), majority of the percentage changes in model resistivity ranged from -80 to 150%. In contrast, after six hours measurement, the range of percentage changes in resistivity significantly become wider to about -80% up to 450%. The drastic change between the two short periods was caused by the active hydrodynamic saltwater intrusion when the level of seawater gradually increased until it reaches maximum high tides.

Semi confined aquifer system (MW3), located about 1.5km from the nearest shorelines, showed that the percentage change in model resistivity was slightly smaller than MW7. The percentage ranged from -45% to 65%. The smaller range of the percentage change of resistivity showed that the hydrodynamic dispersions were not that active compared to the unconfined aquifer. This is due to the distance of the location to the shoreline. The results of time-lapse for the other aquifers showed that the percentage changes of resistivity reduced with the distance from the shoreline especially for semi confined aquifers. Most of the saline contamination came from the drainages infiltration, leakage boundaries and direct saltwater intrusion.

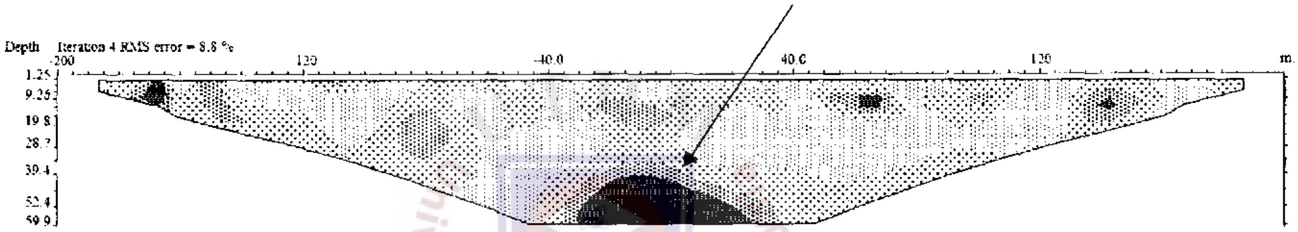
a) After 1 hour of measurement (10.30am-11.30am) (minimum low tide achieved at 8.25am)



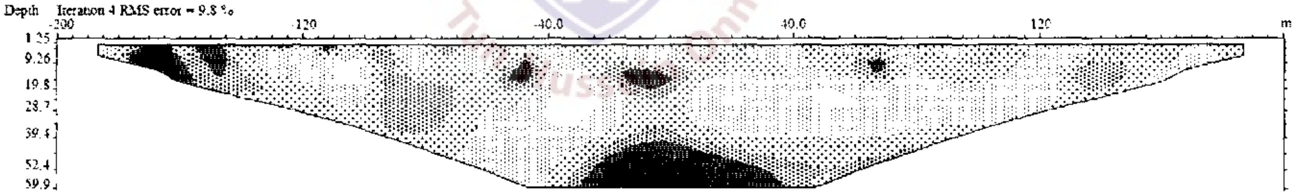
b) After 2 hours of measurement (11.30am-12.30pm)



c) After 3 hours of measurement (12.30pm-1.30pm)



d) After 4 hours of measurement (1.30pm-2.30pm) (maximum high tide achieved at 2.25pm)



e) After 5 hours of measurement (2.30pm-3.30pm)

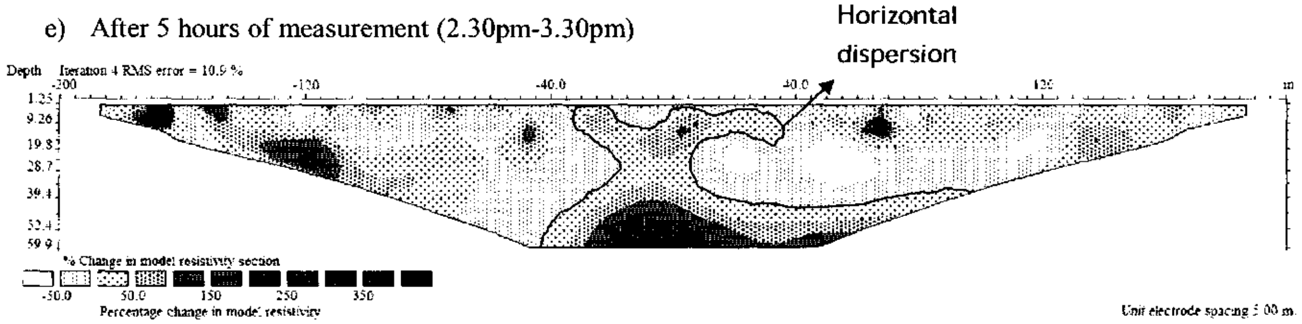
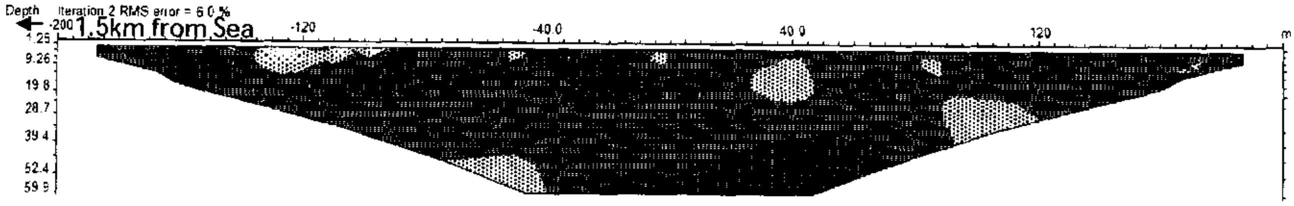
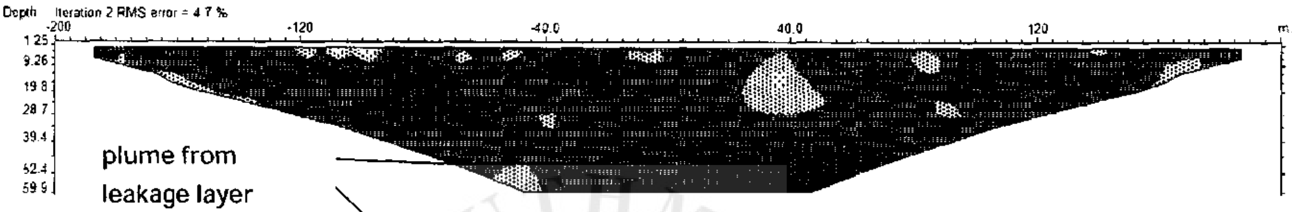


Figure 3: Electrical images monitoring changes in the unconfined aquifer (MW7) on 30th August 2009

a) After 1 hour of measurement (11.00 am-12.00 am) (maximum high tide achieved at 9.25 am)



b) After 2 hours of measurement (12.00 pm-1.00 pm)



c) After 4 hours of measurement (2.00 pm-3.00 pm) (minimum low tide achieved at 3.25pm)

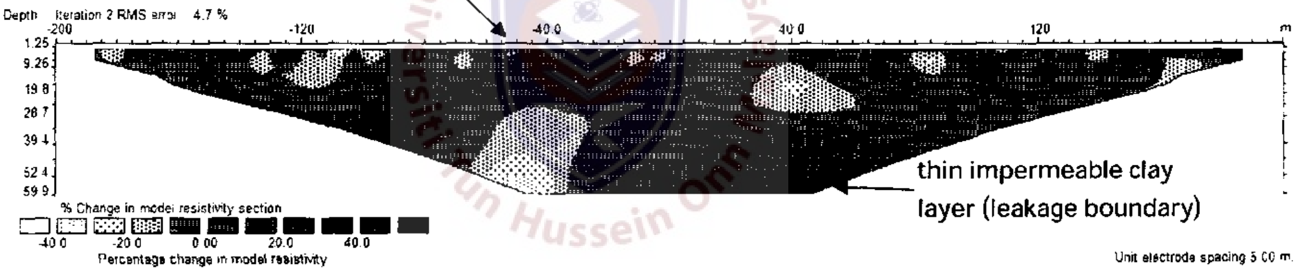


Figure 4: Electrical images monitoring changes in the semi confined aquifer (MW3) on 25th August 2009

4. CONCLUSIONS

Carey Island has gone through land transformation from promontory land to an island that changed the hydrology and hydrogeology cycle which in directly caused constant depression of seawater to the groundwater system. The lack of fresh water recharge to the island caused the water body of the island to be in saline condition all the time and contributed to the salinity of the groundwater system. The time-lapse images showed that the sources of salinity to the groundwater system also contributed by the leakage boundaries and direct saltwater intrusion. It is expected that the percentage changes of resistivity will be reduced during the wet season. The results of this study will assist the modelers to understand the complexity of the hydrogeology condition of the area.

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