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Geoelectrical Investigation Along Miri Coast, East Malaysia: Evaluate the Vulnerability of Coastal Aquifer

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Abstract—The coastal zones are subject to rapid development with growing and conflicting demands on the natural resources, and often they are subject to irreversible degradation. Many coastal aquifers around the world are experiencing some level of salinity encroachment. The most common geophysical method used for the groundwater investigation is Geoelectrical method. In this study, a total of 15 vertical electrical sounding (VES) were carried out using Schlumberger electrode arrangement along Miri coast. The field data was interpreted by using curve matching techniques using IPI2Win software. 53% of the area is dominated by 'Q' type curve indicates decreasing resistivity with depth. The resistivity spatial maps and pseudo cross-sections reveal that the low-resistivity values were observed in the northern side of the study area due to the natural saline water intrusion in the deeper aquifer and anthropogenic influence in the shallow aquifer.

1. Introduction

Recently, coastal areas are subject to fast encroachment due to various activities that often results to irreversible degradation. Many coastal aquifers around the world are experiencing differential level of salinization caused by both natural and man-made processes. Monitoring and identifying the origin of the salinity are crucial for both water management and remediation. There are many researchers have studied seawater intrusion issues around the world [1] – [12].

For groundwater investigation, geophysical methods are widely used because of non-invasive and relatively cheaper [13] – [14]. Vertical electrical sounding (VES) method is more appropriate for groundwater investigation at various geological conditions to access the sub-surface geoelectrical layers [15] – [17]. VES instrumentation is simple and easy to operate in the field compared to other methods [18] – [19]. The data from the VES survey is used to determine the resistivity and thickness of water bearing formation [20] – [21].

The proposed study area, Miri City in East Malaysia is a coastal region. Increased urbanization, industries and agricultural activities has attracted its attention towards saline water intrusion and other anthropogenic influence into the coastal aquifers. To map the migration and extent of saline water

plumes is a tedious job and costly due to the three dimensional nature and expense in drilling deep wells. The method most commonly used for salt water investigations is geo-electrical method. So far no attempt has been made to identify the salt water intrusion along the Miri coast using Geoelectrical method. Hence, this study aims to determine the extent of saline water intrusion in the coastal aquifer with respect to depth. The study also aims to identify the other anthropogenic impacts on the coastal aquifers. The outcome of this research will helps the policy makers to save the groundwater resource in this fragile coastal environment.

2. Study Area

The proposed study area is located in the coastal track of Miri City, Sarawak State, Malaysia as shown in Figure 1. The coastal region of Miri is mostly covered with alluvial sediments and geologically the surrounding area is belonging to the Middle Miocene Miri Formation (85% sand and 15% clay) [22]. River Baram is one of the major rivers in the Sarawak State, which is located in the north side of the study area. River Miri is in the central part of the study area. The study area as shown in Figure 2 are mostly covered by urban settlement and one third of the area is covered with oil palm plantations and afforested areas in the northern side.
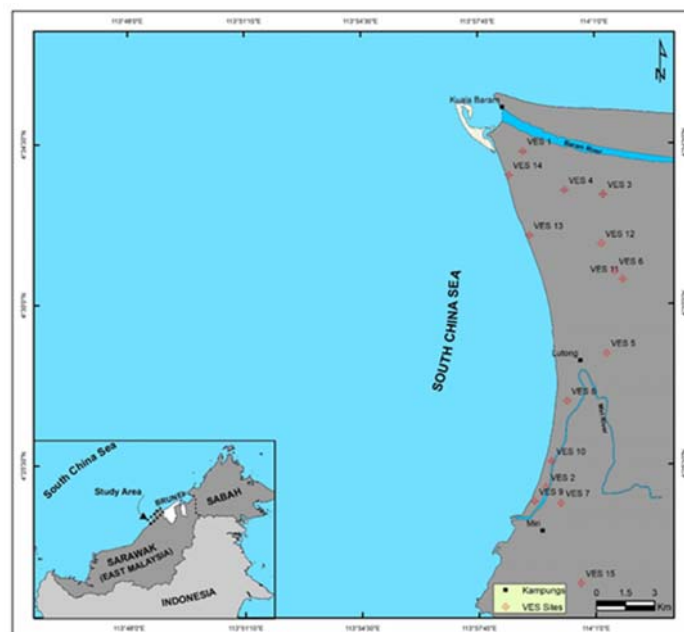

Figure 1. Location map and VES points in the study area

The climate in this region is controlled by northeast (October to March) and southwest (May and September) monsoons. The rainfall ranges from 3,000 to 4,000 mm was recorded in Sarawak state. The average temperature of this region is very stable (26ºC) throughout the year.
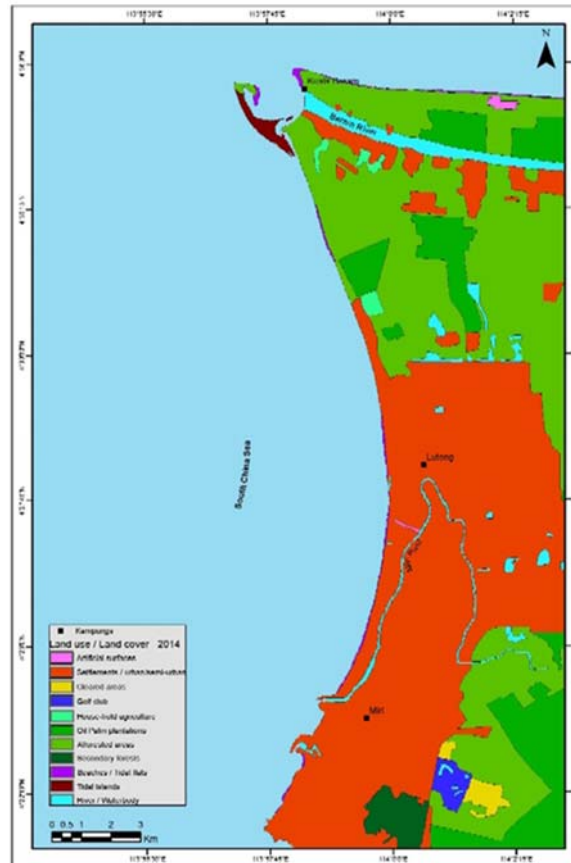
Figure 2. Land use map of the study area

3. Materials and Methods

Totally 15 VES soundings has been carried out using Schlumberger array method along the coastal region of Miri city. In the Schlumberger array, the inner electrical potential electrodes were kept at a fixed spacing and the outer transmit current electrodes are moved further apart. The electrical potential difference at the center of the array decreases rapidly as the outer current electrodes spacing is increased. The spacing between the inner current electrodes must be periodically increased. In this survey, PASI Earth Resistivity Meter (Model. No.16GL-N) was used. The VES data collected from the field are interpreted using IPI2 Win (version 2.0) software to get the master curve types (A, Q, H, K). The resistivity and thickness of sub-surface layers were identified. Spatial maps were produced using inverse distance weighted (IDW) interpolation method of ArcGIS (ver. 10.2) and the pseudo cross-sections were prepared using IPI2 Win software. In addition to that, 8 soil samples were collected at the VES survey points and the soil salinity were measured using standard procedures [23].

4. Results and Discussion

4.1. VES Data

VES data were evaluated by curve matching techniques for 15 locations are shown in Table 1. From the results, 53% of this region dominated by Q type of curve indicates the resistivity values are gradually decreased ($\rho1 < \rho2 < \rho3$). VES location numbers 2, 3, 5, 6, 7, 11, 13 and 14 are of Q type as shown in Figure 3. 33% of area represented by H type indicate that a low resistivity layer is sandwiched

between the top soil and sand layer of high resistivity. VES location numbers 4, 8, 9, 10 and 12 are of H type. 14% of this region are in K and KA types indicating few weaker zones. VES location numbers 1 and 15 are of K and KA types. In general, three major zones were delineated as top soil, sand layer and clay layer in the study area.

Table 1. Resistivity and Thickness of Geoelectrical Section

VES no	Resistivity (in ohm-m)					Thickness (in m)					Curve Type
	Layer					Layer					
	1	2	3	4	5	1	2	3	4	5	
1	6.38	214	0.905			0.5	0.836	∞			K
2	686	128	6.23			0.812	6.06	∞			Q
3	5391	160	16.2	1.14		0.5	2.01	6.76	∞		Q
4	502	1.7	945			2.5	15	∞			H
5	1398	242	5.91			1	3.49	∞			Q
6	459	65.9				1.43	∞		∞		Q
7	563	130	14.8			1.22	5.56	∞			Q
8	1093	206	8.38	38		1.47	2.11	15.6	∞		H
9	2987	311	30.2	10.3	2896	1	3.44	9.92	41.9	∞	H
10	1438	13.2	2265			2.83	18.7	∞			H
11	7479	584	0.225			3.76	24.5	∞			Q
12	6142	237	2808			3.9	14.4	∞			H
13	420	8.49	0.0652			2.04	47.6	∞			Q
14	14938	309	8.89	0.0097		1	6.08	26.8	∞		Q
15	31.3	70.6	4.19	383		2.65	4.45	23.8	∞		KA

The first layer of resistivity values varied from 6.38 to 14938 Ωm and with layer thickness ranged from 0.5 to 3.9 m. The higher resistivity value of 14938 Ωm was observed at VES number 14, while minimum resistivity was observed in VES number 1. The maximum thickness was attained in VES number 12 and minimum thickness was noted at VES number 1. Mostly, high resistivity values were recorded in first layer with varying thickness is due to the presence of top soils [14]. Spatial variation of resistivity maps shows that higher resistivity values are observed in the northern region and lower resistivity values are noted in southern part of the study area as shown in Figure 4a. It is evident that the northern side is mostly covered by oil palm plantation and afforestation, where the excavation of top soils is quite common. In this region, the soil salinity was also higher due to the plantation activities as shown in Figure 5.

The second layer of resistivity values ranged from 1.7 to 584 Ωm and thickness of layer varied from 0.836 to 47.6 m. A higher resistivity value of 584 Ωm was noted at VES number 11, whereas lower resistivity value of 1.7 was observed at VES number 4. The spatial map of second layer shows a very distinct spots of low resistivity values in the north eastern side as shown in Figure 4b. This is due to the infiltration of urban sewage water and industrial effluent discharge into the subsurface.
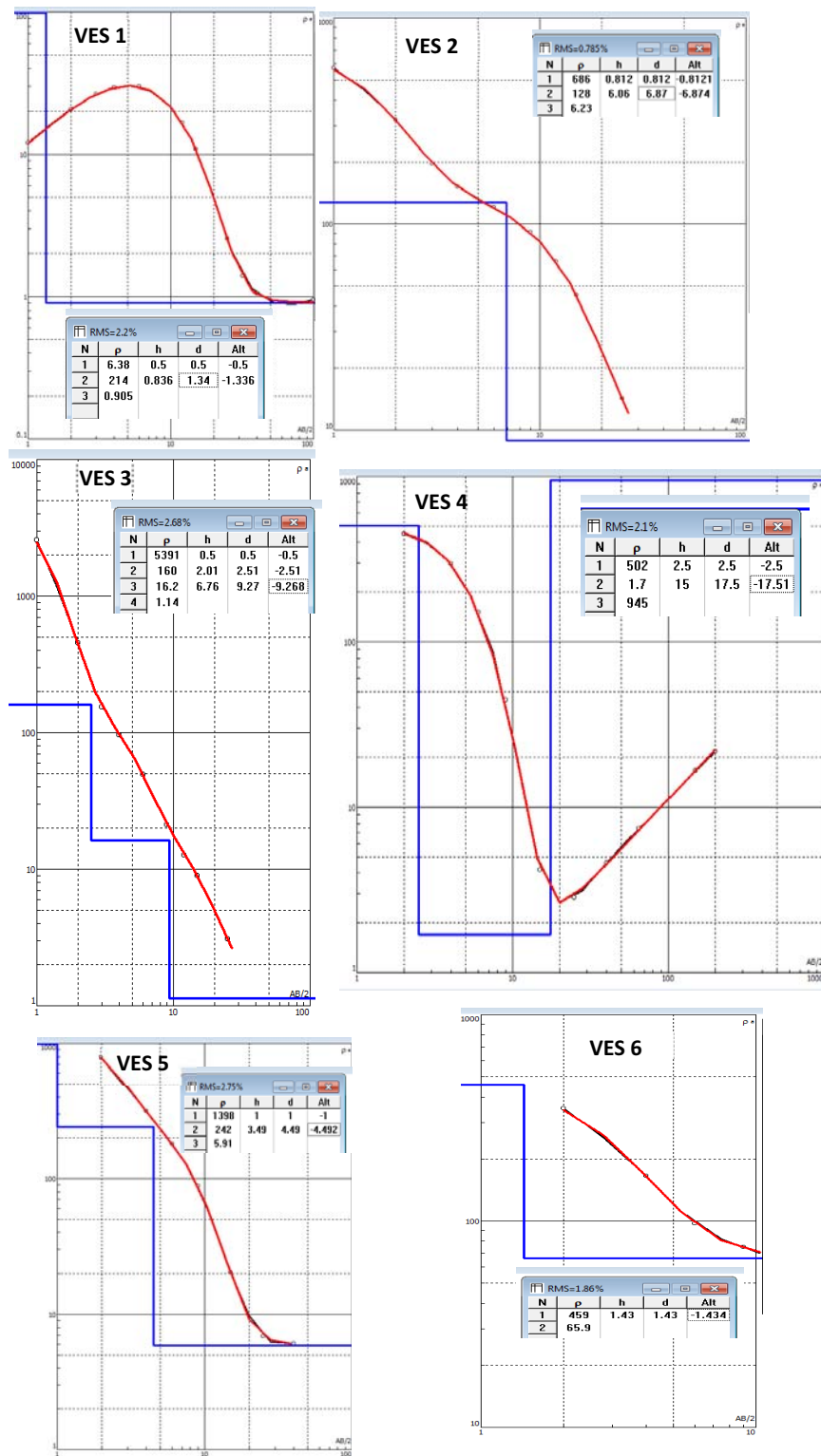
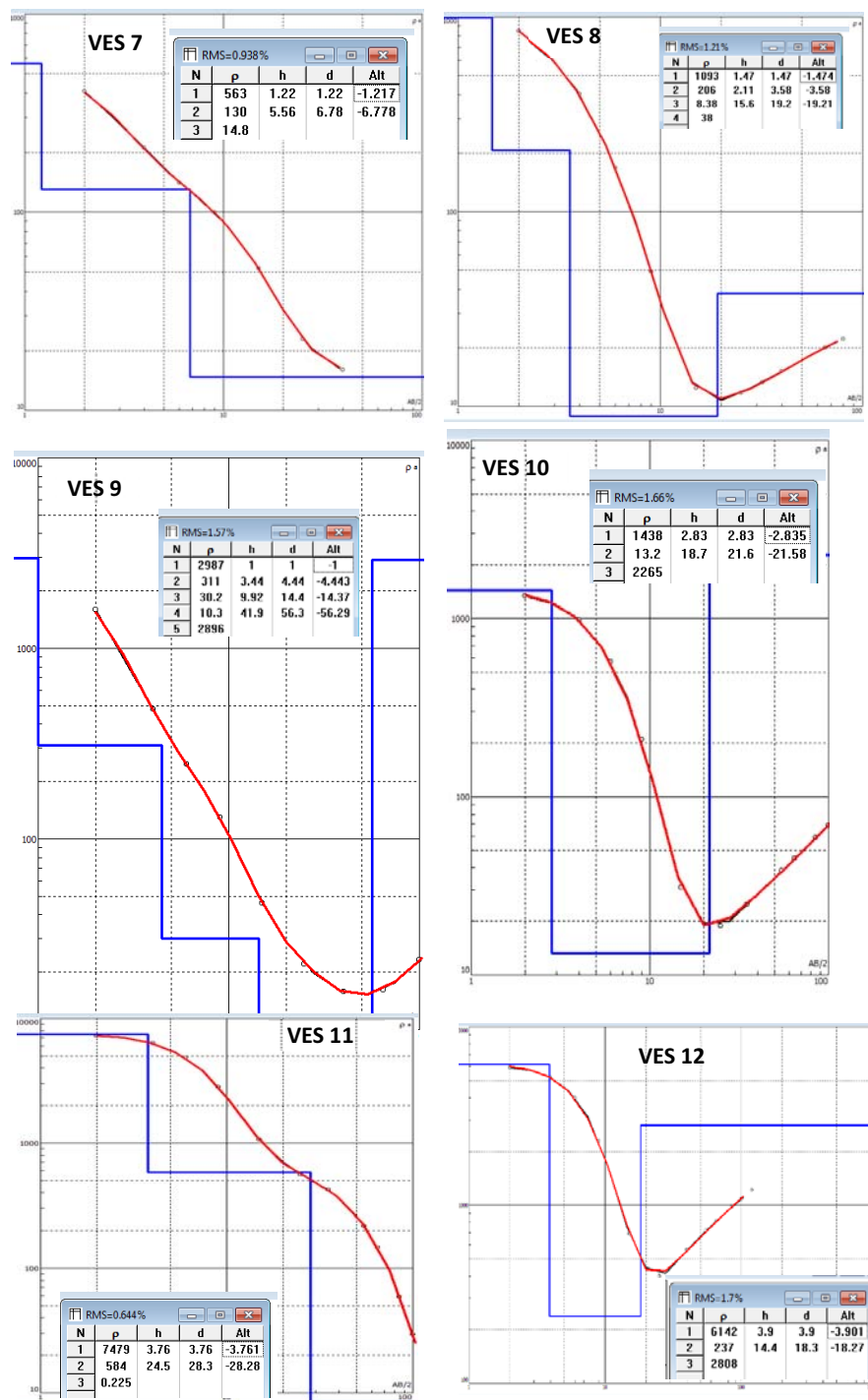**Figure 3**. VES curve results of the studied locations.
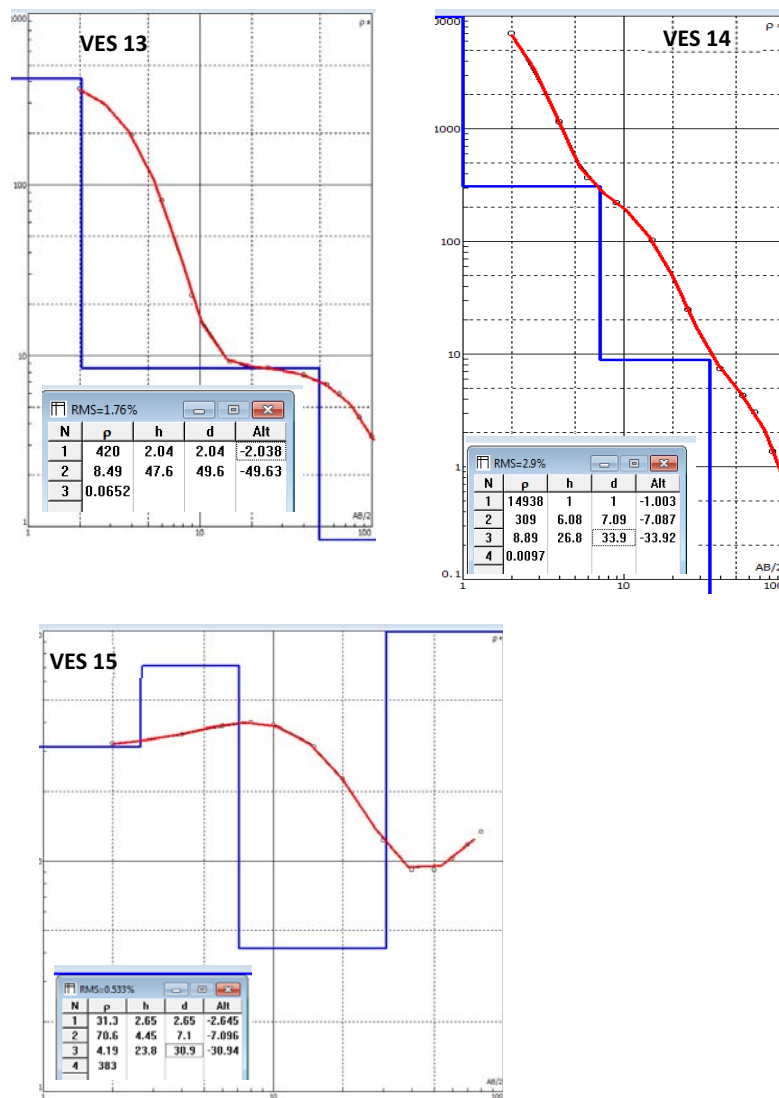
Figure 3. continued
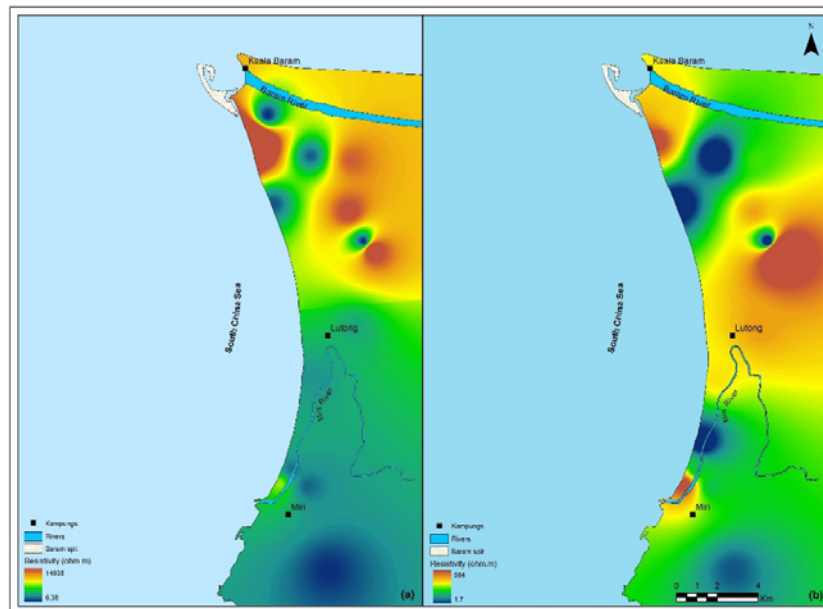
Figure 3. continued

Figure 4a and 4b. Spatial variation of resistivity for Layer 1 and 2

The third layer of resistivity values ranged from 0.065 to 945 Ωm. But mostly lowest resistivity values are observed in this layer due to the presence of clayey layer. This layer shows that the low resistivity values are distributed as patches in different location from north to south indicates multiple activities.
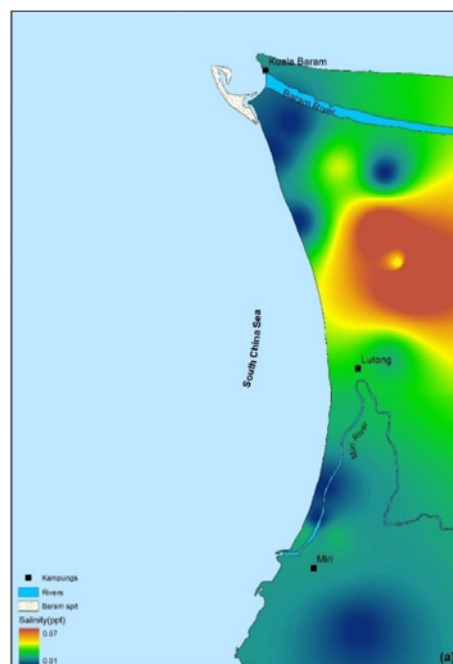

Figure 5. Soil Salinity Spatial Map

4.2. Cross-Sections

For qualitative interpretation, pseudo cross sections were made in the study area to decipher the resistivity distribution in the subsurface using IPI2 win software. Two cross sections were selected, in which section 1 is parallel and section 2 is perpendicular to the coast.

Pseudosection 1: This section line was made along VES numbers 14, 13, 8, 10 and 9 from north to south, which is parallel to the coast as shown in Figure 6. A thick layer of low resistivity value (>3 Ωm) at a depth of 70m was observed in VES number 14 and thinning out gradually towards VES no. 13. This layer is restricted within VES no. 14 and extended to 13. The reason for this low resistivity zone is the natural sea water intrusion due to its proximity to the coast and also supported by the Baram river discharge.
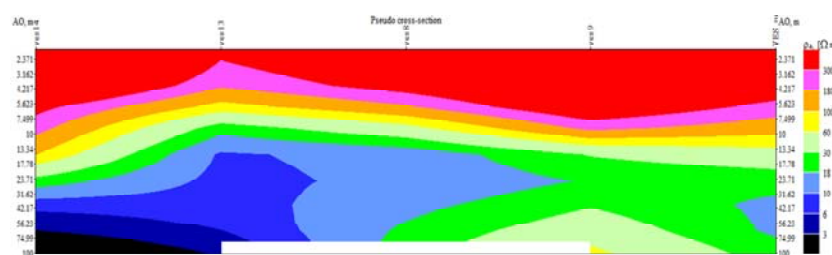

Figure 6. Pseudo cross-section 1

Pseudosection 2: This section line was made along VES numbers 14 and 4 from west to east, which is perpendicular to the coast as shown in Figure 7. In VES number 14, a very thin layer of low resistivity layer of >2 Ωm at a depth of 75m was observed. This is again confirmed by the natural sea water intrusion. Another thick layer of low resistivity value of >5 Ωm at a depth of 14m was observed. This is due to the leaching of secondary salts into the shallow aquifer due to oil palm plantation activities.
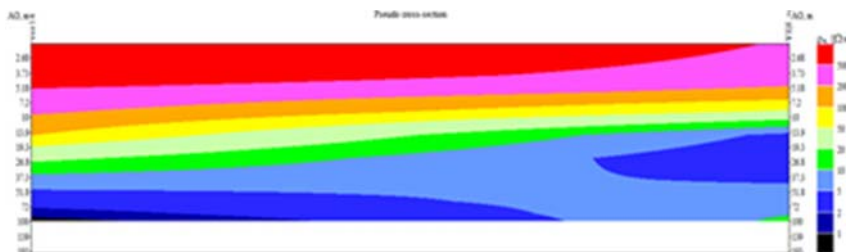

Figure 7. Pseudo cross-section 2

5. Conclusion

Geoelectrical studies indicate that three major zones were delineated as top soil, sand layer and clay layer in the study area. Interpreted master curves are mostly three-layered curves, namely Q type followed by H, K and KA type. Q type curve is dominant indicates the resistivity values are gradually decreased with depth ($\rho1 < \rho2 < \rho3$). The high resistivity in the first layer is due to the presence of top soil. The low resistivity in the shallow aquifer is due to the leaching of secondary salts from the oil palm plantation. The low resistivity in the deeper aquifer is due to the saline water intrusion. In general, northern side has more stress to the quality of coastal aquifer compared to southern side. Hence, some sustainable management plans are need to this coastal aquifer for future needs.

6. Acknowledgements

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