Chapter 6

Result and Discussion of Area 3

6. 1. Introduction

Area 3 covers the coastal area from Bachok, Tawang, Sabak, Pengkalan Chepa, and the surrounding area to the landward. It covers an area with a width of approximately 7 km from the beach line, with a total area of 171 km^2. The map of Area 3 and its land uses are shown in Figure 6.1.

The land uses in the southeastern area are mainly for paddy planting. In Bachok, season crops planting, such as tobacco, corn, chilli, and other vegetable plants, is the dominant agricultural activity. In the Pengkalan Chepa and Sabak areas, the dominant agricultural activity is the production of coconuts. The use of chemical fertilizers in Area 3 to enhance agricultural production is less than in Area 1 where the palm oil plantations are predominant. However, the impact of the fertilizer use on the groundwater in Area 3 must be considered.

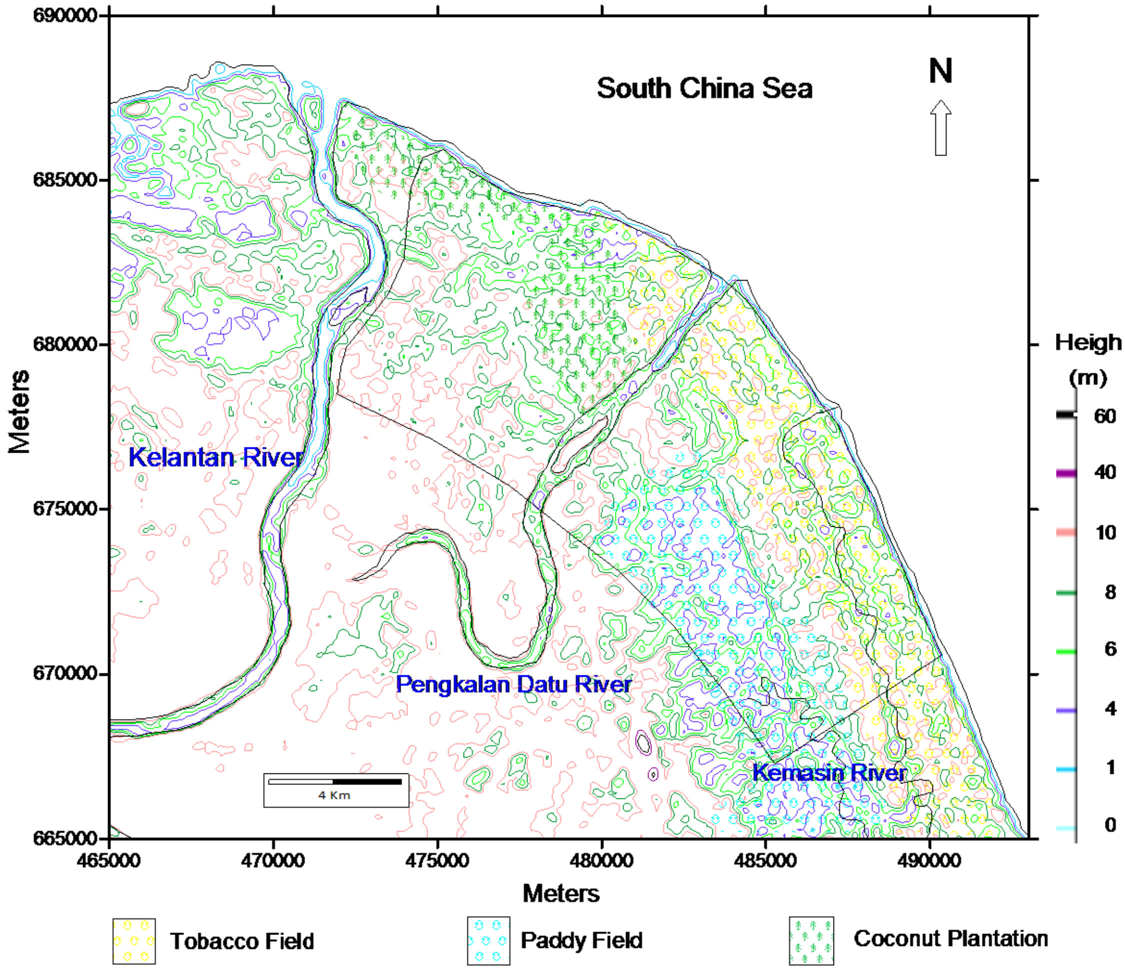


Figure 6.1. The location map of Area 3 and its land uses.

The people who live in Kota Bharu, Pengkalan Chepa, and Bachok mainly use groundwater for their daily activities, and this water is supplied by the domestic water company (Air Kelantan Sdn Bhd). In order to meet the domestic demand, pumping activities are more intensive in certain areas. Pumping well stations are located at Tanjung Mas, Jalan Merbau, Pengkalan Chepa, and Kampung Chap. On the other hand, some rural communities use groundwater from shallow aquifers for drinking water and other domestic usages. They develop conventional wells that are less than 10 m deep. Since Area 3 is near the coastline, it must contain seawater intrusion, which can result from high water extraction rates or the existence of ancient brackish water that has been trapped in the subsurface for a long period of time.

In this chapter, the results of the study and the associated discussion are divided into the following three parts:

1. The first discussion focuses on a study of the variation of the salt water content in soils that have different characteristics. This study is needed because the northeast portions of Area 3 are bounded by the South China Sea. The objective of this study is to characterize the geoelectrical resistivity of various soils that contain differing amounts of salt water. The results can be used as a calibration standard for subsequent studies.
2. The second discussion is to explore the groundwater problem throughout Area 3. Emphasis will be placed on identifying groundwater pollutants, including potential nitrate contamination and salt/brackish water in the aquifer. In addition, this discussion will address the interrelationships that exist between the various groundwater aquifers.
3. The third discussion will focus on detecting and monitoring nitrate concentrations, especially in the Bachok area where the use of fertilizer occurs from time to time. This discussion will also include the sources of the nitrates and the specific mechanisms by which they infiltrate the soil.

6.2. Resistivity Characterization in Soil Saturated Seawater Mixture

The soil samples used for this study were obtained from various representative locations. A hand auger was used to collect the soil samples. The locations from which the samples were taken are given in Figure 6.2. Two soil samples were taken from each location. The soil samples were collected from a marine deposit zone (SL01 and SL02), a sand bar in the Pangkalan Datu River (SL03 and SL04), and from a flooded zone (SL05 and SL06). The soils were excavated at a depth of 1 m below the surface to avoid the humus layer and roots, placed in plastic bags where their original temperature was maintained, and transported to the laboratory.

In the laboratory, each soil sample was divided into seven portions. The basic tests, such as grain size distribution, were performed on one portion of the soil samples. The other portions were used to measure the resistivity of the soil with different amount of seawater content. The soil samples were saturated with water containing different amount of seawater, and five resistivity measurements were conducted for each soil sample. Measurements of soil resistivity were conducted using a Terrameter SAS 4000 resistivity meter in the geophysical laboratory in the Department of Geology, University of Malaya.

6.2.1. Grain Size Distribution

The grain size distributions for all soil samples are given in Table 6.1. The highest total percentage of sand (94.6%) is in sample SL04, which is made up predominantly of medium-sized sand particles. The sample also contains 4.9% gravel, whereas silt and clay make up the remaining 0.5%. Sample SL04 has a greater percentage of gravel and a lower percentage of silt and clay than sample SL03. However, the soil samples taken from the flooded area (SL05 and SL06) are made up predominantly of fine-grain sand and medium-grain sand. In the marine area, soil samples (SL01 and SL02) consists of fine sand (94%), followed by medium sand (3%). These samples have the highest percentage of silt and clay among all the sample.

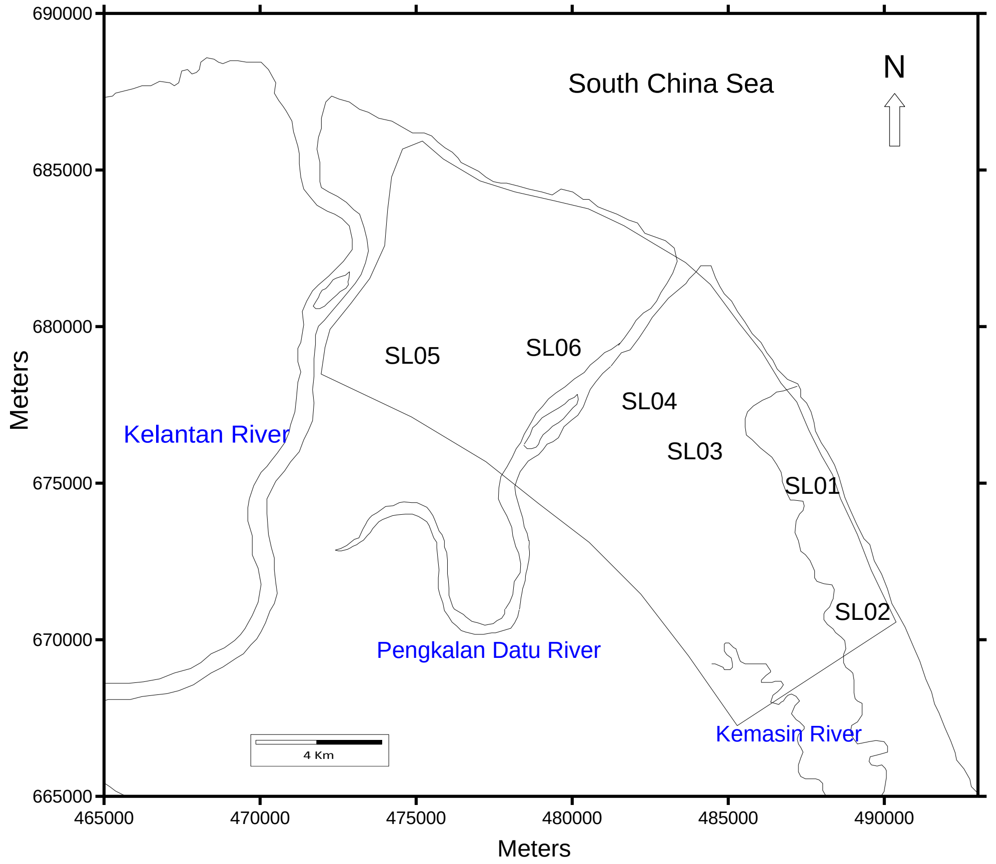


Figure 6.2. Location of soil samples.

Table 6.1 Grain size distribution of the selected locations.

Sample ID	Samp Location	Sampling Depth (m)	Gravel (%)	Coarse Sand (%)	Medium Sand (%)	Fine Sand (%)	Silt & Clay (%)
SL01	Bachok	1	0.000	0.000	3.034	94.671	2.295
SL02	Bachok	1	0.000	0.000	2.945	94.750	2.306
SL03	Tawang	4.5	5.130	18.326	59.737	16.521	0.286
SL04	Tawang	1	4.930	16.402	59.156	19.093	0.419
SL05	Tanjung Mas	1	0.000	0.026	2.891	95.986	1.097
SL06	Kp. Panchor	1	0.000	0.364	7.125	91.515	0.996

Generally, coarse sand, medium sand, and gravel are found in the samples from the sand bar in the Pengkalan Datu River, while fine sand is predominant in the sample from the flooded area. At the marine deposit area, fine sand is predominant, but the samples also had the highest percentages of silt and clay among all the samples.

6.2.2. Chemical Content of Seawater and Seawater-freshwater Mixtures

The major chemical seawater and fresh-sea-water mixtures content are given in Table 6.2. Chloride is the highest concentration in each of the water samples, followed by sodium and sulphate. In sample SW05 (5% seawater mixture), the chloride concentration is 568 mg/L. The chloride concentration increases linearly with as the percentage of seawater content increase (SW10-SW100). The same linear trend also is observed for the other seawater chemical components.

To show a correlation between the percentages of seawater content and the chemical content, the data in Table 6.2 is presented as a scatter plot in Figure 6.3. The increasing percentages of seawater content in the samples are followed by corresponding, linear increases of the chemical content. A high correlation (R^2 value) is obtained with value near 1 for every chemical concentration. This implies a very good measurement (precise and accurate).

Table 6.2 Major chemical content of water sample with variation of sea water content. Chemical content of seawater derived from Honslow (1995) can be found in the bottom of the table.

Sample ID	Sea Water (%)	Chloride (mg/L)	Sulphate (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)
SW00	0	11	4	2.277	11.34	0.647	2.21
SW05	5	488	78	29.01	25.09	50.28	Sat
SW10	10	1188	161	57.91	37.48	87.59	Sat
SW25	25	4052	226	115.4	88.91	264.2	2477
SW50	50	7443	869	192.4	186.6	655.4	4881
SW75	75	10619	1183	298.5	284.1	995.7	7942
SW100	100	16719	1939	378.1	399.8	1275	10682
Hounslow	Seawater	19000	2700	390	410	1350	10500

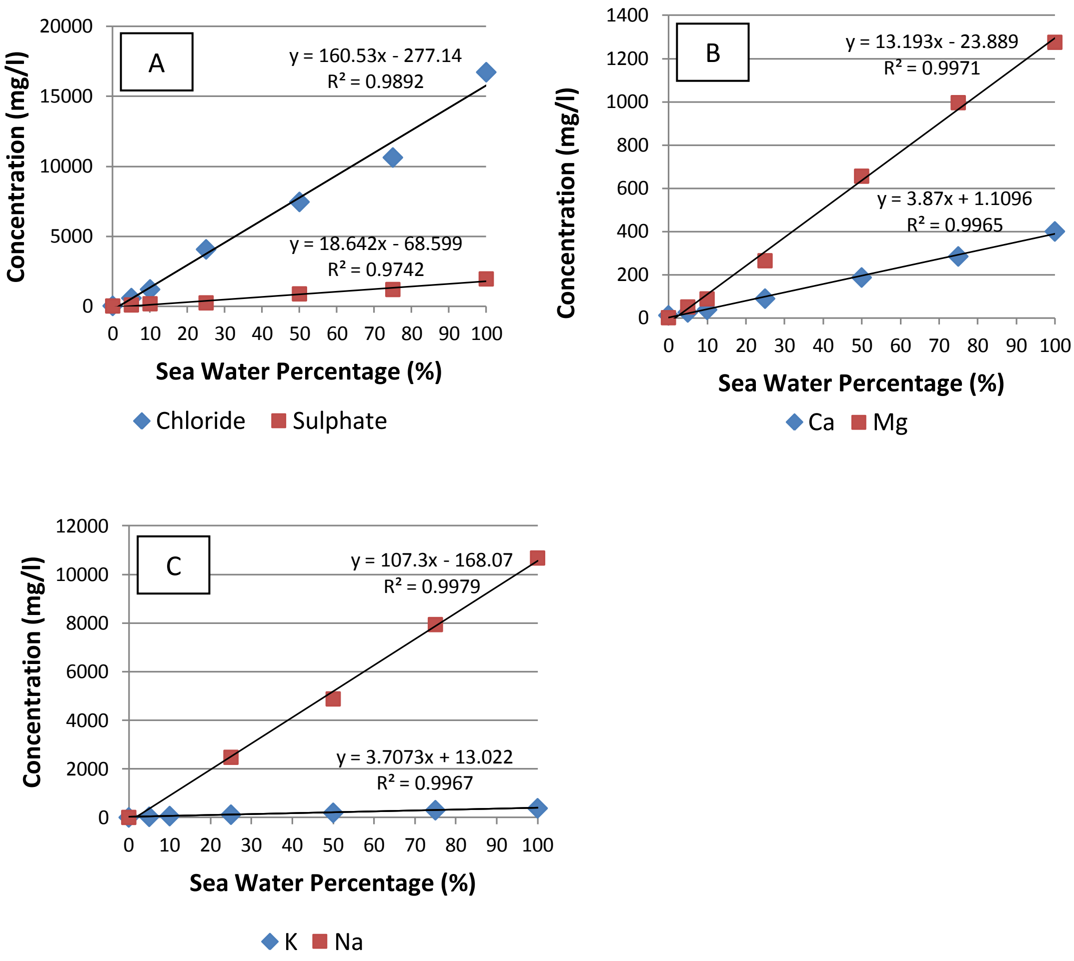


Figure 6.3. Chemical concentration in the water with variation percentage of sea water, (A). Chloride and Sulphate, (B). Ca and Mg (C).K and Na. The Rsquare (near to 1) indicate good correlation between measured data.

6.2.3. Correlation of Soil Property and Resistivity Measurement

Table 6.3 shows the results of direct resistivity measurements for several soils saturated with water containing different percentages of seawater. Plot of this data is given in Figure 6.4 (A). In the soil saturated with water that contained no seawater, the lowest resistivity value is obtained in the sample SL01, followed by sample SL02. Samples SL01 and SL02 are the soil samples collected from the marine deposit. The lowest resistivity value for samples from the marine deposit is 0.687 ohm.m, which is obtained for sample SL01 when it is saturated with 100% seawater.

In the soil samples collected from Tawang (SL03 and SL04), which are identified as clean sand, the highest resistivity value of 45.728 ohm.m is obtained for sample SL04 when it is saturated with water that contained no seawater. The lowest resistivity value (0.756 ohm.m) for the samples from Tawang is in the sample that is saturated with 100% seawater.

The lowest resistivity value for the soil samples from the marine deposit and Tawang occurred in samples saturated with 100% seawater, and the value obtained was very similar. However, there is a large difference between the highest resistivities of the samples from these two sites that were saturated with water with no seawater.

In the samples collected from flooded zone, the highest resistivity value of 113.35 ohm.m was found in SL005. The value is significantly greater than the highest resistivities for the other samples. The lowest value for a sample from this zone was 1.732 ohm.m for SL06, which was saturated with 100% seawater.

Based on this resistivity measurement, it can be concluded that by increasing the percentage of seawater content, the resistivity value decreases drastically. The total anion content of water in the soil pores has a significant effect on resistivity readings, as shown in Figure 6.4 (B). It is also quite remarkable that the figure shows that resistivity appears to be extremely sensitive to small changes in the total anions. When the seawater content was changed from 0% to 10%, resistivity value decreased drastically to about 10-18 ohm.m. Meanwhile, when seawater content was increased above 10%, resistivity value decreased only slightly. The source of the soil samples and the percentage of clay content in the samples also influence the resistivity value. The marine deposit and the flooded zone do not significantly have different contents of fine sand. However, in the marine deposit, the residual concentration of anions from the seawater is higher than the concentration of anions in the flooded zone deposit. This result in reduced resistivity value in the marine deposit compared to the flooded zone deposit for the same concentration of seawater. The amount of silt and clay content in the soil also affect the resistivity value. Increasing the clay content of the soil reduces its porosity, resulting in an increase in the resistivity value. Generally, resistivity value for soil filled by brackish seawater will be less than 15 ohm.m.

Table 6.3. Direct resistivity measurement in the soil saturated with seawater variation.

Seawater (%)	SL001 (ohm.m)	Stdev	SL002 (ohm.m)	Stdev	SL003 (ohm.m)	Stdev	SL004 (ohm.m)	Stdev	SL005 (ohm.m)	Stdev	SL006 (ohm.m)	Stdev
0	14.790	0.005	15.390	0.010	44.451	0.331	45.728	0.379	113.350	0.042	108.641	0.022
5	5.764	0.047	5.954	0.041	10.857	0.022	11.152	0.024	23.030	0.011	21.879	0.005
10	4.154	0.021	4.261	0.024	6.683	0.020	6.803	0.020	12.138	0.003	11.506	0.003
25	3.127	0.025	3.190	0.010	4.969	0.020	4.991	0.022	9.423	0.008	9.115	0.008
50	2.305	0.004	2.337	0.026	2.380	0.005	2.400	0.005	4.956	0.011	4.766	0.003
100	0.687	0.003	0.689	0.002	0.756	0.002	0.759	0.001	1.758	0.034	1.732	0.014

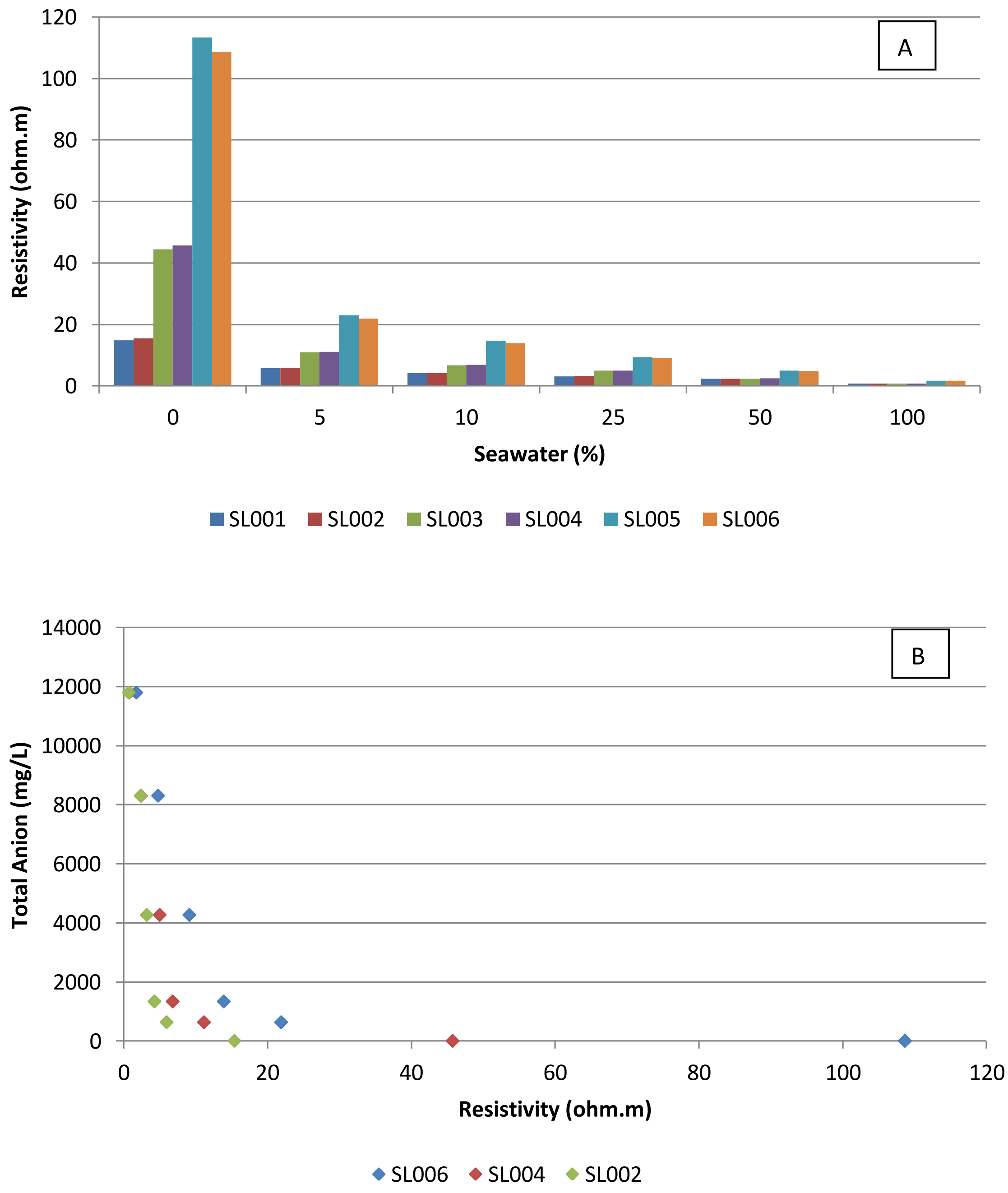


Figure 6.4. (A) Resistivity versus amount of seawater (%) in different soil sample. (B) Total anion versus direct resistivity reading. Resistivity value decrease drastically when the soil saturated by even low amount of seawater content.

Based on the soil properties, hydrogeochemical, and direct geoelectrical resistivity measurement, as discussed above, the summary of geoelectrical characters in different soil characteristics with different pore water content can be concluded in Table 6.4.

Table 6.4. Geoelectrical resistivity value in different soil characteristics with different pore seawater mixture content

No	Dominant Medium	Moisture Content	Seawater Content (%)	Resistivity (± 5%) Ω.m	Field (ohm.m)
1	Medium and coarse sand	Saturated	0	45	30-60
2	Medium and coarse sand	Saturated	5	11	8 - 15
3	Medium and coarse sand	Saturated	10	6.7	< 5
4	Medium and coarse sand	Saturated	25	4.9	< 5
5	Medium and coarse sand	Saturated	50	2.3	< 5
6	Medium and coarse sand	Saturated	100	0.75	< 5
7	Fine sand (flooded zone)	Saturated	0	110	95 - 125
8	Fine sand (flooded zone)	Saturated	5	22	18 - 25
9	Fine sand (flooded zone)	Saturated	10	12	8 - 15
10	Fine sand (flooded zone)	Saturated	25	9.2	7 - 11
11	Fine sand (flooded zone)	Saturated	50	4.8	< 5
12	Fine sand (flooded zone)	Saturated	100	1.7	< 5
13	Fine sand (marine deposit)	Saturated	0	14.5	13 - 16
14	Fine sand (marine deposit)	Saturated	5	5.8	5 - 7
15	Fine sand (marine deposit)	Saturated	10	4.2	< 5
16	Fine sand (marine deposit)	Saturated	25	3.1	< 5
17	Fine sand (marine deposit)	Saturated	50	2.3	< 5
18	Fine sand (marine deposit)	Saturated	100	0.6	< 5

6.3. Groundwater Investigation for Area 3

A combination of hydrogeochemical and geoelectrical resistivity techniques were used to study the groundwater problem in this area. The water pollution within the shallow aquifer including nitrate pollutant is one of the targets. This is because the nitrate can potentially contaminate the shallow aquifer (Saadi et al., 2003). Additionally, the first (shallow) aquifer from dug well is the main water resource for rural domestic especially in Bachok and Tawang area. Other water resources are obtained from a water company (Air Kelantan Sdn Bhd) that extracts groundwater from deeper aquifers (second and third aquifers). This study is carried out to investigate these aquifers characteristic.

As in Area 2, the hydrogeochemical data obtained from this study (primary data), together with the hydrogeochemical data from Jabatan Mineral dan Geosains Malaysia (secondary data), were used in the interpretation. The groundwater samples were obtained at various depth from several wells. In the pumping well stations, the water samples were collected from the deepest aquifer (131 m depth) to the shallower aquifer (14 m depth). While, the water samples were collected from dug wells or piezometers with depth of less than 7 m.

In addition to the hydrogeochemical investigation, geoelectrical resistivity survey was conducted to determine the characteristics of the subsurface materials and the groundwater properties in the aquifers.

6.3.1. Hydrogeochemical Results

Figure 6.5 shows the location of groundwater samples. The results of hydrogeochemical analysis of the groundwater samples are given in Table 6.5. The primary data which were collected in the field during the research is presented without underline and the secondary data collected from the Jabatan Mineral dan Geosains Malaysia are presented with underline.

In Table 6.5, seventeen percent of the hydrogen ion concentrations (pH) in groundwater samples are slightly acidic and twenty nine percent are slightly alkaline. They are generally good for drinking and some other domestic uses. Magnesium ion's (Mg^{2+}) concentration is generally low. The presence of magnesium ion in the shallow groundwater aquifer especially in the area of well named with WA3 (no 1-8 in Table 6.5) could be explained by the present of magnesium in carbonate powder (neutralising agent) distributed by the farmer before cultivation. Other possibilities of magnesium source are due to fertilizing activities especially by using chemical fertilizer containing of MgO (Table 6.5). However, the magnesium content in the groundwater is generally safe for human use (WHO, 1984).

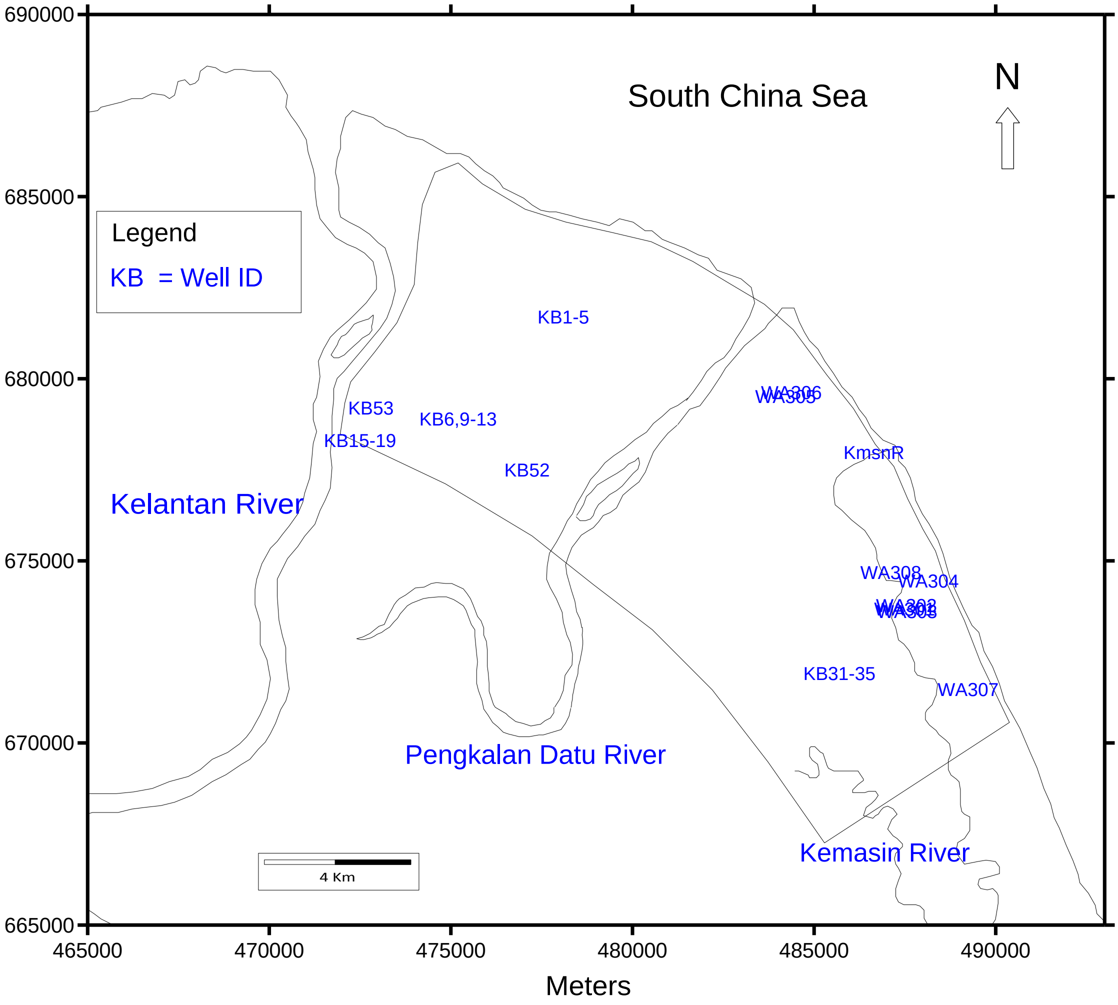


Figure 6.5. Location of groundwater sampling. The groundwater samples are collected from shallow aquifer (wells starting with WA3) to deeper aquifer (wells starting with KB)

Table 6.5. Water chemistry results for Area 3. The non underlined sample is the primary field data and the underline sample is the secondary data derived from Jabatan Mineral dan Geosains Malaysia

No	Sample ID	Location X	Location Y	Well Depth (m)	Ground Level (m)	Depth to Water (m)	Wtr.L (msl)	TDS mg/L	Cond µS/cm	Sal 0/00	T C	pH
1	WA301	487496	673681	3.82	5	2.22	2.78	344	706	0.3	29.5	7.5
2	WA302	487544	673777	3.56	5	2.38	2.62	349	717	0.3	29.5	7.3
3	WA303	488149	674452	3.18	4	2.38	1.62	289	595	0.3	29.8	7.8
4	WA304	486669	676702	4.12	5	2.33	2.67	421	861	0.4	29.7	7.2
5	WA306	484219	679517	6.12	8	1.5	6.5	348	715	0.3	28.9	7.7
6	WA305	484809	678385	3.48	8	0.5	7.5	297	611	0.3	28.3	7.9
7	WA307	489246	671471	5.3	5	1.1	3.9	572	984	0.3	28.3	7.7
8	WA308	487115	674683	<6	10	2.3	7.7	427	863	0.1	28.1	7.6
9	<u>KB1</u>	<u>478100</u>	<u>681700</u>	100	5.93	5.03	0.9	100	185	None	None	7.2
10	<u>KB2</u>	<u>478100</u>	<u>681700</u>	87	5.93	5	0.93	106	197	None	None	7.1
11	<u>KB3</u>	<u>478100</u>	<u>681700</u>	68.5	5.87	4.99	0.88	380	624	None	None	7.1
12	<u>KB4</u>	<u>478100</u>	<u>681700</u>	59.5	5.85	4.95	0.9	426	698	None	None	6.7
13	<u>KB5</u>	<u>478100</u>	<u>681700</u>	24.5	5.79	4.42	1.37	2594	5100	None	None	7.1
14	<u>KB6</u>	<u>475200</u>	<u>678900</u>	129	4.48	8.71	-4.23	72	89	None	None	7.3
15	<u>KB9</u>	<u>475200</u>	<u>678900</u>	55.5	4.49	7.73	-3.24	126	194	None	None	8.0
16	<u>KB10</u>	<u>475200</u>	<u>678900</u>	31.5	4.65	6.25	-1.6	512	1048	None	None	7.4
17	<u>KB11</u>	<u>475200</u>	<u>678900</u>	32	4.5	6.11	-1.61	278	570	None	None	8.1
18	<u>KB12</u>	<u>475200</u>	<u>678900</u>	32	4.49	6.08	-1.59	516	1069	None	None	8.2
19	<u>KB13</u>	<u>475200</u>	<u>678900</u>	31.5	4.41	6.16	-1.75	512	1188	None	None	6.4
20	<u>KB15</u>	<u>472500</u>	<u>678300</u>	126.5	6.57	5.49	1.08	230	85	None	None	6.9
21	<u>KB16</u>	<u>472500</u>	<u>678300</u>	110	6.58	5.43	1.15	130	177	None	None	7.3
22	<u>KB18</u>	<u>472500</u>	<u>678300</u>	65	6.55	5.56	0.99	110	170	None	None	7.1
23	<u>KB19</u>	<u>472500</u>	<u>678300</u>	28.5	6.47	5.37	1.1	140	190	None	None	7.3
24	KB22	486500	664700	50.4	3.61	1.4	2.21	50.4	106.6	0	30.6	6.1
25	KB23	486500	664700	32.4	3.58	2.07	1.51	95.6	200	0.1	30.6	6.1
26	KB24	486500	664700	9.4	3.61	1.67	1.94	26.5	56	0	30.6	6.1
27	<u>KB52</u>	<u>477100</u>	<u>677500</u>	21	4.91	None	None	96	151	None	None	7.0
28	<u>KB53</u>	<u>472800</u>	<u>679200</u>	14	2.52	6.24	-3.72	96	175	None	None	8.0
29	KB31	485700	671900	131.4	3.39	2.84	0.55	498	1014	0.5	28.7	6.8
30	KB32	485700	671900	101.2	3.6	2.8	0.8	167.6	384	0.2	28.7	7.5
31	KB33	485700	671900	83.4	3.33	2.85	0.48	943	1883	1	28.9	7.2
32	KB34	485700	671900	40.4	3.34	3.1	0.24	3630	6850	3.7	28.8	6.5
33	KB35	485700	671900	29.2	3.39	2.85	0.54	314	645	0.3	28.8	6.9
34	KmsnR	486650	677970				0	222	459	0.2	30.4	5.8

Table 6.5. (Continued)

No	Sample ID	Chloride mg/L	Nitrate mg/L	Sulfate mg/L	Fluoride mg/L	K mg/L	Ca mg/L	Mg mg/L	Na mg/L	Al mg/L	Fe mg/L	CO3 mg/L	HCO3 mg/L
1	WA301	3.5	0	35.2	0	12.8	104.7	23.9	15.4	0	1.8	2.5	24.4
2	WA302	1.7	0	16.4	0	6.5	101.2	28.6	13.6	0	3.5	2.5	25.1
3	WA303	6.3	0	7	0	3.1	93.1	14	19.9	0	0.1	2.5	33.8
4	WA304	1.5	0.3	52	0	7.1	123	29.6	24.8	0	2	2.5	38.6
5	WA306	4.5	0	24.5	0	2.3	107	24.1	15	0.2	0.9	5	42
6	WA305	4.6	1.4	15.4	0	39	63.1	24.3	15.3	0	0	5.9	30.2
7	WA307	130.4	29.2	83.8	0.1	15.7	61.8	22.7	68	0	0	2.1	31.7
8	WA308	7.2	12.5	0	0	3.5	7.2	3.2	7.6	0.1	0.3	2	39.5
9	KB1	34.0	1.4	<5	<0.5	7.1	14.0	4.3	9.1	0.0	10.0	<1	40.0
10	KB2	33.0	1.1	<5	<0.5	6.8	15.0	6.9	6.7	0.0	13.0	<1	50.0
11	KB3	177.0	2.5	<5	<0.5	8.8	36.0	23.0	27.0	0.0	18.0	<1	23.0
12	KB4	200.0	3.7	<5	<0.5	9.7	37.0	26.0	33.0	0.0	18.0	<1	20.0
13	KB5	1527.0	13.0	<5	<0.5	25.0	30.0	31.0	1028.0	0.0	20.0	<1	121.0
14	KB6	6.0	2.8	<5	<0.5	7.6	2.6	1.9	7.3	0.0	5.8	<1	32.0
15	KB9	21.0	2.8	<5	<0.5	5.5	10.0	6.9	12.0	0.0	9.9	<1	72.0
16	KB10	281.0	1.9	<5	<0.5	10.0	9.5	13.0	142.0	0.0	10.0	<1	91.0
17	KB11	140.0	1.6	<5	<0.5	6.4	13.0	13.0	70.0	0.0	9.1	<1	69.0
18	KB12	298.0	2.9	<5	<0.5	14.7	30.4	27.4	164.8	0.0	17.4	0.0	12.3
19	KB13	368.0	0.6	<5	<0.5	6.5	49.0	49.0	55.0	0.0	20.0	<1	13.0
20	KB15	110.0	3.4	<5	<0.5	11.0	2.6	0.5	85.0	0.0	3.8	<1	36.0
21	KB16	4.0	2.4	<5	<0.5	9.2	26.0	3.2	5.5	0.0	1.6	<1	99.0
22	KB18	6.0	3.2	<5	<0.5	11.0	17.0	4.3	5.9	0.0	7.4	<1	82.0
23	KB19	6.0	1.3	5.0	<0.5	7.8	26.0	1.9	5.9	0.0	2.3	<1	96.0
24	KB22	9.8	0.6	1.3	0.0	4.5	18.3	1.6	7.0	0.0	0.5	0.0	11.4
25	KB23	16.2	0.0	0.0	0.2	6.1	5.4	3.2	52.5	0.0	3.6	3.4	0.0
26	KB24	9.4	0.1	3.2	0.1	2.7	5.3	1.0	7.8	0.0	0.8	3.5	0.0
27	KB52	18.0	7.0	22.0	<0.5	7.2	5.2	2.1	14.0	0.0	0.2	<1	18.0
28	KB53	6.0	4.3	9.0	<0.5	4.5	8.6	2.1	17.0	0.0	0.4	<1	55.0
29	KB31	369.7	0.1	0.3	0.2	42.0	33.1	25.3	157.9	0.0	63.9	0.0	0.0
30	KB32	28.1	0.0	0.1	0.3	14.6	21.0	21.0	50.8	0.0	0.3	7.7	30.7
31	KB33	382.3	0.4	0.7	0.8	26.9	27.7	20.5	119.8	0.0	34.8	31.1	128.7
32	KB34	3206.6	0.0	0.3	0.3	77.7	119.0	123.1	0.0	0.0	6.0	28.6	53.8
33	KB35	83.9	0.1	0.0	0.8	20.3	12.3	19.2	151.3	0.0	0.2	11.4	44.2
34	KmsnR	184.1	0.9	33.0	8.3	10.3	9.3	15.4	0.0	0.3	0.7	0.0	23.0

At the Pengkalan Chepa pumping station (KB1-5), magnesium content in the shallowest well (KB5, 24.5 m) and deepest well (KB1, 100m) is 31 mg/L and 4.3 mg/L, respectively. In this location, the trend of magnesium concentration is decreasing with depth. The magnesium concentration in groundwater from other pumping well station (KB6-14), also show the same trend as KB1-5. However in the shallowest wells (KB11, KB12 and KB13), the magnesium concentration are still higher than the other deeper wells.

There are generally high sodium (Na) and potassium (K) concentration in the groundwater samples especially in the aquifer with depth of 20 to35 m. This is due to the groundwater being contaminated by brackish water trapped in the aquifer (Samsudin, at al., 2007). In the shallow aquifer, occurrence of sodium may be due to the natural system (i.e. rainwater) (Kouzana, L., et al., 2008; Leboeuf, 2004; Kim, Y., et al., 2003).

In the shallow aquifer (starting with well WA3), the chloride concentration is generally low (< 10 mg/L). The influence of marine shale may have been a contributory factor of the chloride content in the northern part of the study area. The highest chloride content (130 mg/L) can be found in well WA307 where it is located around 200 m from the beach line. The chloride concentration in the water samples are within the accepted limits for human consumption.

In the deeper aquifer (pumping well station), relatively higher chloride concentration of more than 1000 mg/L was observed in all wells with depths ranging from 25 m to 40 m. However, at Tanjung Mas pumping well station, chloride concentration ranges from 298 to 368 mg/L. Based on laboratory study as in the previous subchapter (Subchapter 6.2), this value indicates that groundwater is predicted to be containing a mixture of fresh water plus 4 % of seawater. However, in the deeper aquifer, the chloride concentrations are within the acceptable limits for human consumption (< 250 mg/L).

In general, most ions are positively correlated with chloride ions. K, Ca, Mg and Na show a strong correlation with chloride in the deeper aquifer (Figure 6.6), indicating that such ions are derived from the same source of saline waters. The Bivariate plots of chemical constituents in groundwater for deeper aquifer are presented in Log scale due to relatively higher gap among the values. The relationship between Cl/HCO3 ratios and chloride also shows mixing of fresh groundwater and seawater, and the samples with lower ratios can be characterized as fresh waters (Kim, Y., et al., 2003).

Figure 6.7 show the correlation between K, ca, Mg and Na with chloride content for shallow aquifer. The shallow aquifer is contradictory to the deeper aquifer. In the shallow aquifer, most ions exhibit a bad correlation. It indicates that such ions are derived from a different source. This is due to the presence of well WA307 (see Figure 6.7.). The well WA307 is very near to the beach, so that the water sample in this well indicates the occurrence of brackish water. High chloride concentration in the WA307 well was because of its distance of around 500 m from the beach line and well depth below -30 cm relative to the mean sea level.

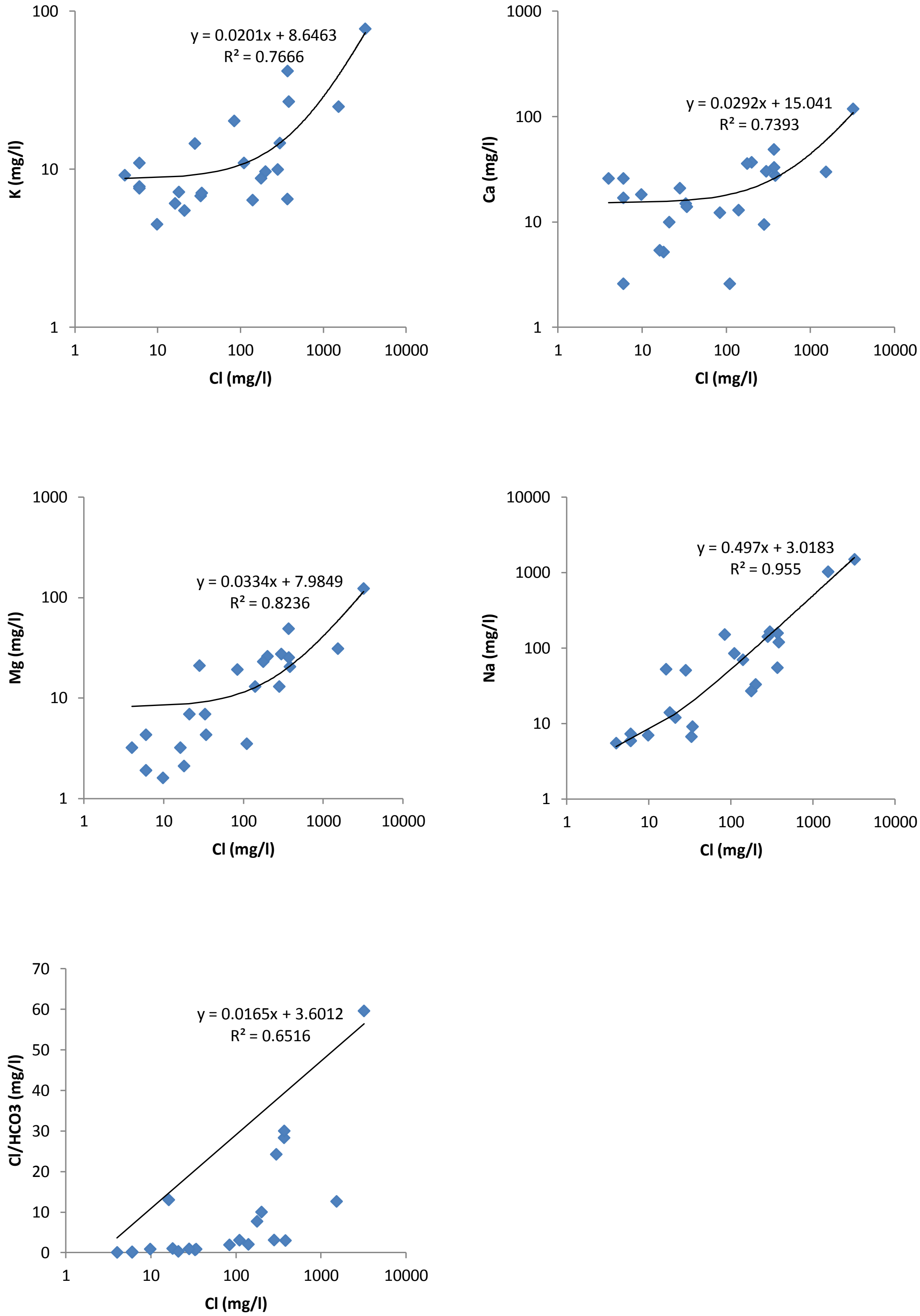


Figure 6.6. Bivariate plots of chemical constituents in groundwater for deeper aquifer.

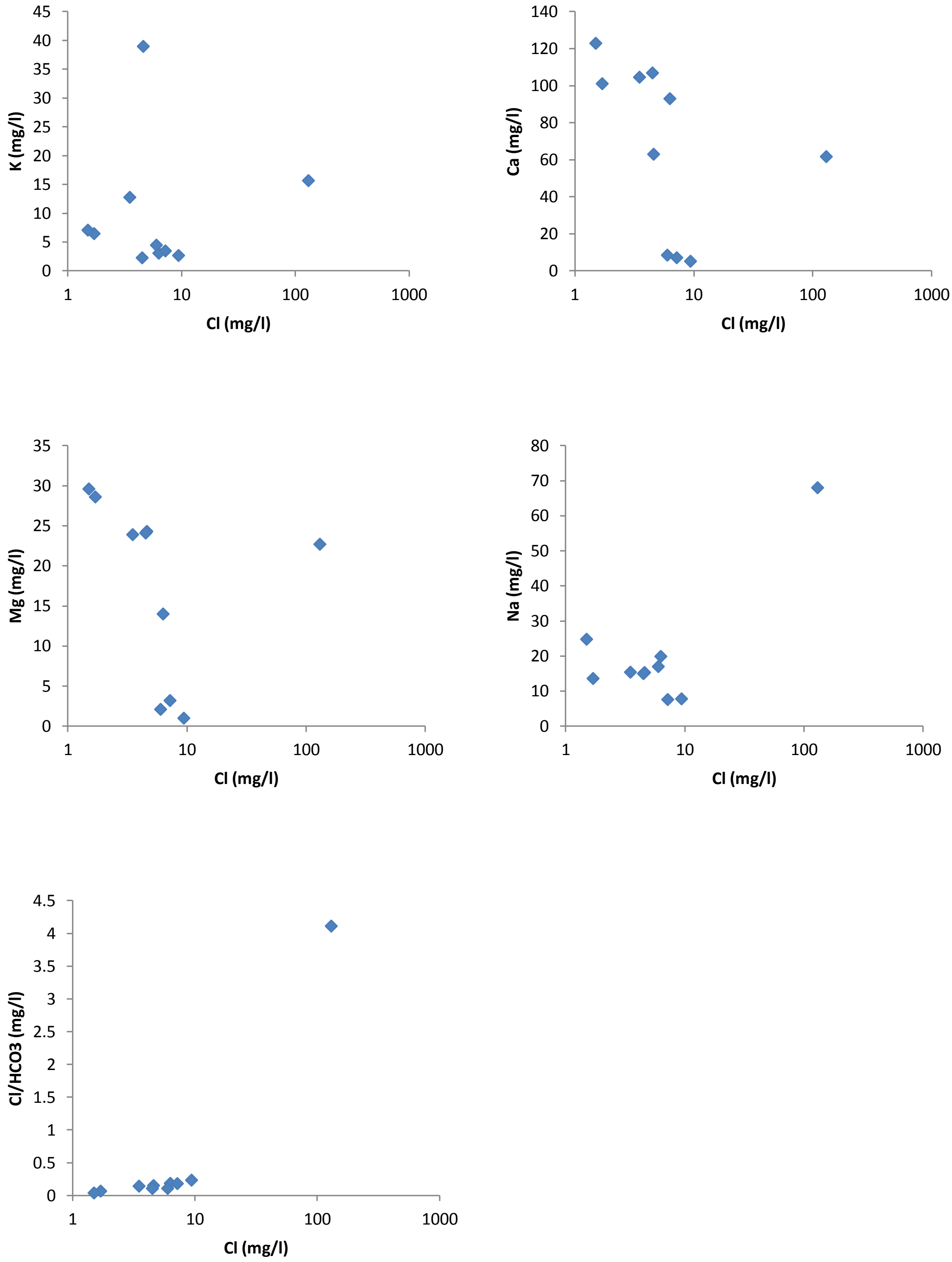


Figure 6.7. Bivariate plots of chemical constituents in groundwater for shallow aquifer.

In the shallow wells (starting with WA3), relatively higher nitrate concentration is observed at wells A307 (29.2 mg/L) and A308 (12.5 mg/L). While, in the other shallow wells, nitrate concentration vary from 0 to 1.4 mg/L. Nitrate concentration in groundwater does not show any specific correlation with depth. The potential source of nitrate in the area of shallow wells may include animal excrements and agriculture activities (chemical fertilizers usage). In the area around the well WA307 and WA308, after the tobacco season is ended, the farmers plant corn and other vegetable planting.

In the deeper wells (starting with KB), the highest nitrate concentration of 13 mg/L is found in the shallowest well (KB5, 24.5 m depth) at Pengkalan Chepa well station. This may be due to the accumulation of nitrates from the surface to the aquifer through the semi confined material. Whilst in the other wells, nitrate concentration is ranging from 0 to 4 mg/L. Generally, the nitrate concentration tends to be higher during intensive agriculture activity. However, it is still in within accepted limit for human consumption (less than 45 mg/L).

6.3.2. Geoelectrical Resistivity Result

In Area 3, thirty one lines of geoelectrical resistivity surveys have been conducted out of the lines for chemical fertilizer monitoring in last subchapter (Subchaper 4.4). The map location of geoelectrical resistivity survey is shown in Figure 6.8. The survey was started at Tanjung Mas pumping well station. In this site, gamma ray log data that is used for calibration and standardization (subsurface correlation). Furthermore, the result obtain in subchapter 4.2 (Table 6.4) plus direct field resistivity measurement are used for geoelectrical model interpretation. The following termination will be used as labels in the geoelectrical models: CSL = compacted soil with low moisture content; GB = granite basement; SA = shallow aquifer; PA = Potential aquifer;

FBW = fresh-brackish water interface; BFW = brackish-fresh water interface; ~5% = about 5% salt fresh water mixture in aquifer.

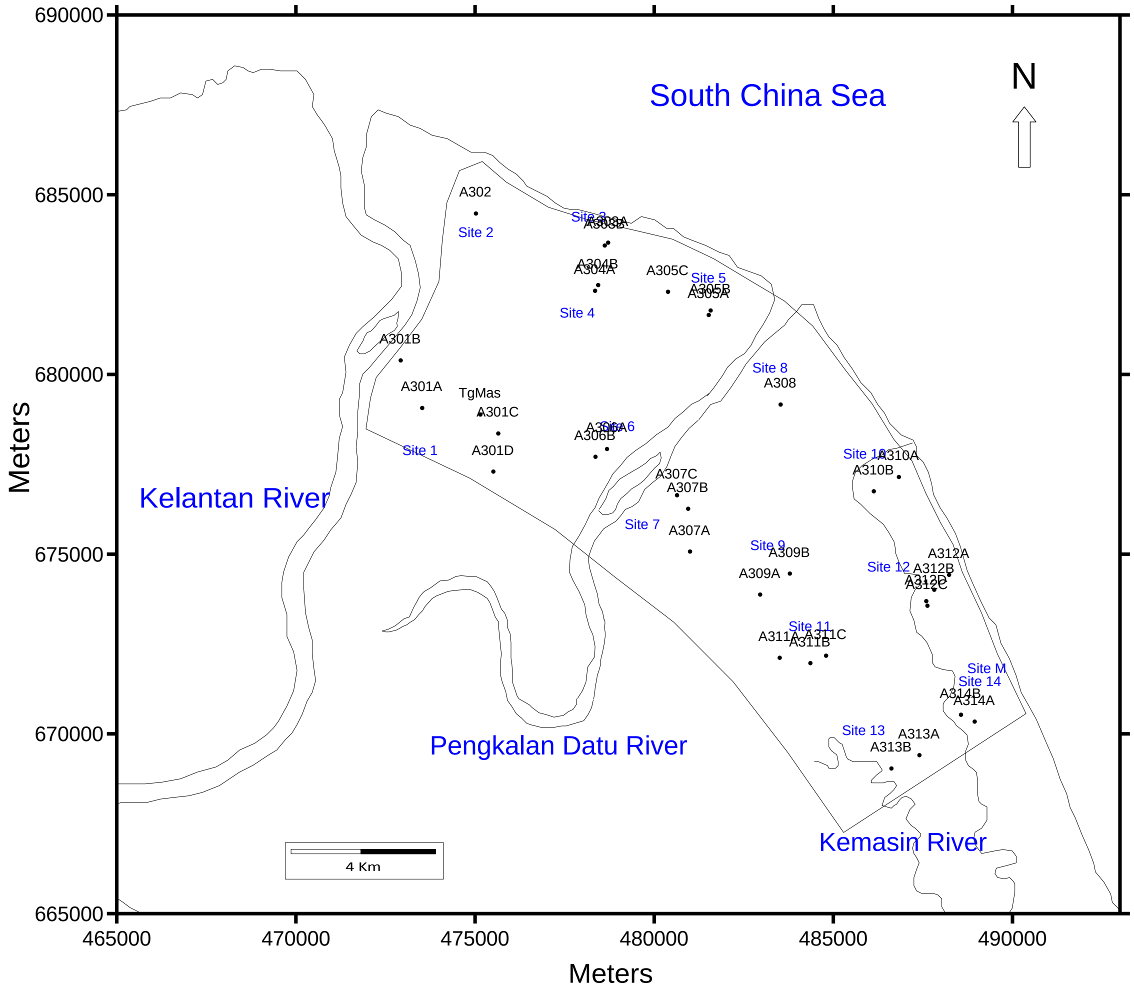


Figure 6.8. Map of Geoelectrical resistivity survey lines location.

Site 1

At site 1, geoelectrical resistivity survey began from the Tanjung Mas pumping well station. The other lines (A301A, A301B, A301C and A301D) were located surrounding the Tanjung Mas pumping well station. There were five monitoring wells with variations of depth within this pumping station. The wells are KB6 (129 m depth), KB7 (99 m depth), KB8 (88 m depth), KB9 (55.5 m depth) and KB10 (31.5 m depth) as given in Figure 6.9. There was however not enough space to lay long cable for geoelectrical resistivity survey. A grass field of 100 m long was used for geoelectrical resistivity survey with 2.5 m electrodes spacing. The survey line was intersected the monitoring well which had gamma ray data and 3 m perpendicularly away from the well to avoid the well effect in the geoelectrical resistivity reading.

Figure 6.9 shows the subsurface lithology derived from the gamma ray log interpretation. Relatively higher gamma ray value is obtained on the surface until around 2 m depth, corresponds to the unit of clay. Below this depth to a depth of 8 m, relatively lower gamma ray is observed and interpreted as fine sand formation. Figure 6.10 shows the geoelectrical model for this site survey line. A relatively higher resistivity value of about 200 ohm.m is observed near surface at the position of 0-20 m mark and 80-100 m mark. The geoelectrical model is also supported by five direct surface resistivity measurements which have an average of 225.02 ohm.m with 52.53 ohm.m standard deviation at the zone around 0-20 m mark. This corresponds to the clayey soil with low moisture content. There was no rain for the past 1 week before conducting the survey. However, relatively lower resistivity value (80-120 ohm.m) is observed in the 20-80 m zone. This corresponds with wet clayey soil because of the water spill.

A resistivity value of about 20-40 ohm.m is observed at depth of 5.5 to 1.5 m, corresponding to the saturated fine sand formation. This interpretation is supported by the gamma ray log data that shows fine sand formation within the depth interval. In the deeper zone, clay material is observed within an interval of around 8-12 m (0 to -4 m) in depth in the gamma ray log data. At the same depth interval in the geoelectrical model shows relatively higher resistivity value about 120 ohm.m. Visually, the correlation of subsurface lithology derived from the interpreted gamma ray data and geoelectrical model is quite good.

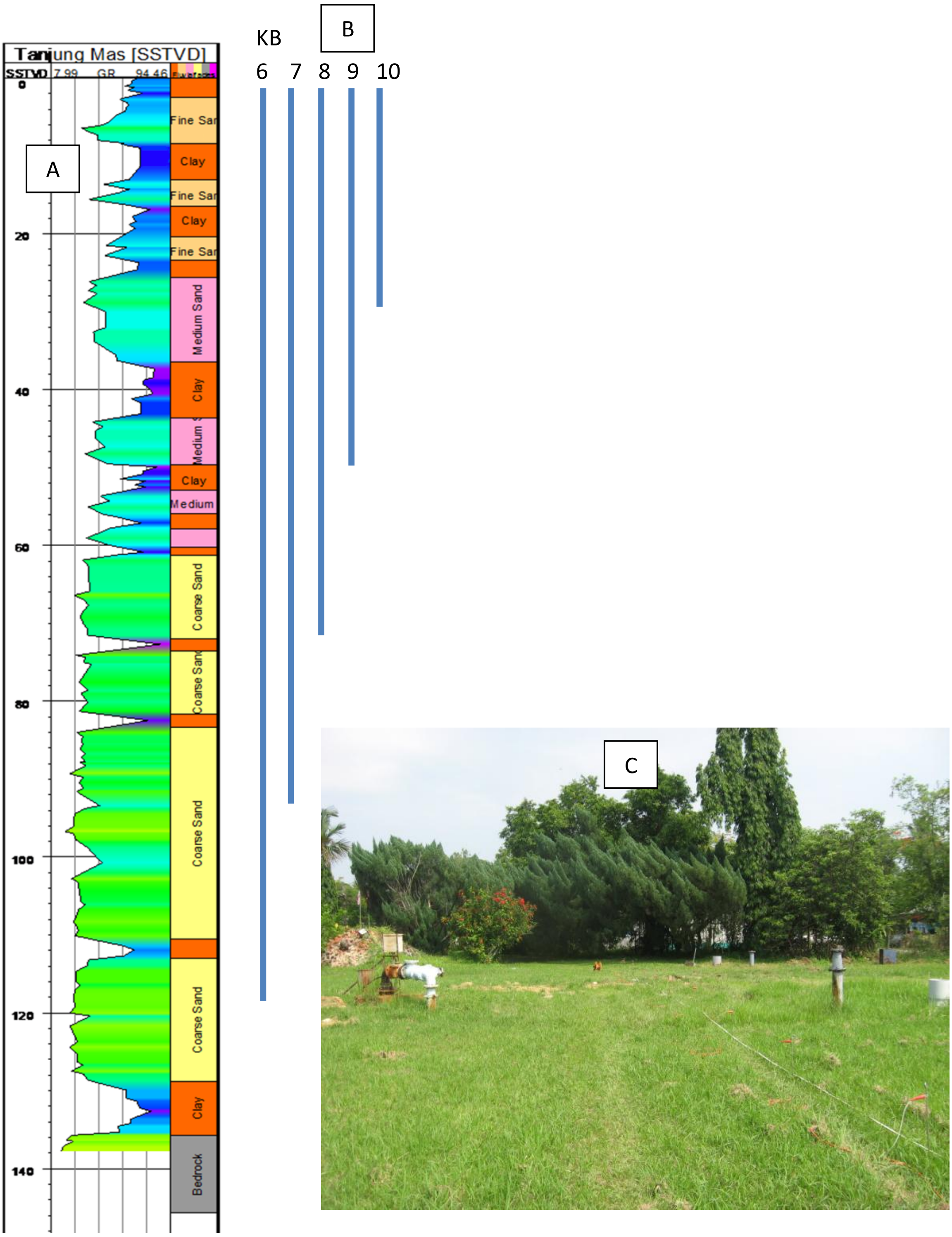


Figure 6.9. (A) Lithology of Tanjung Mas subsurface derived from interpretation of gamma ray data. (B) Five monitoring well with true scale. (C) View around the survey area.

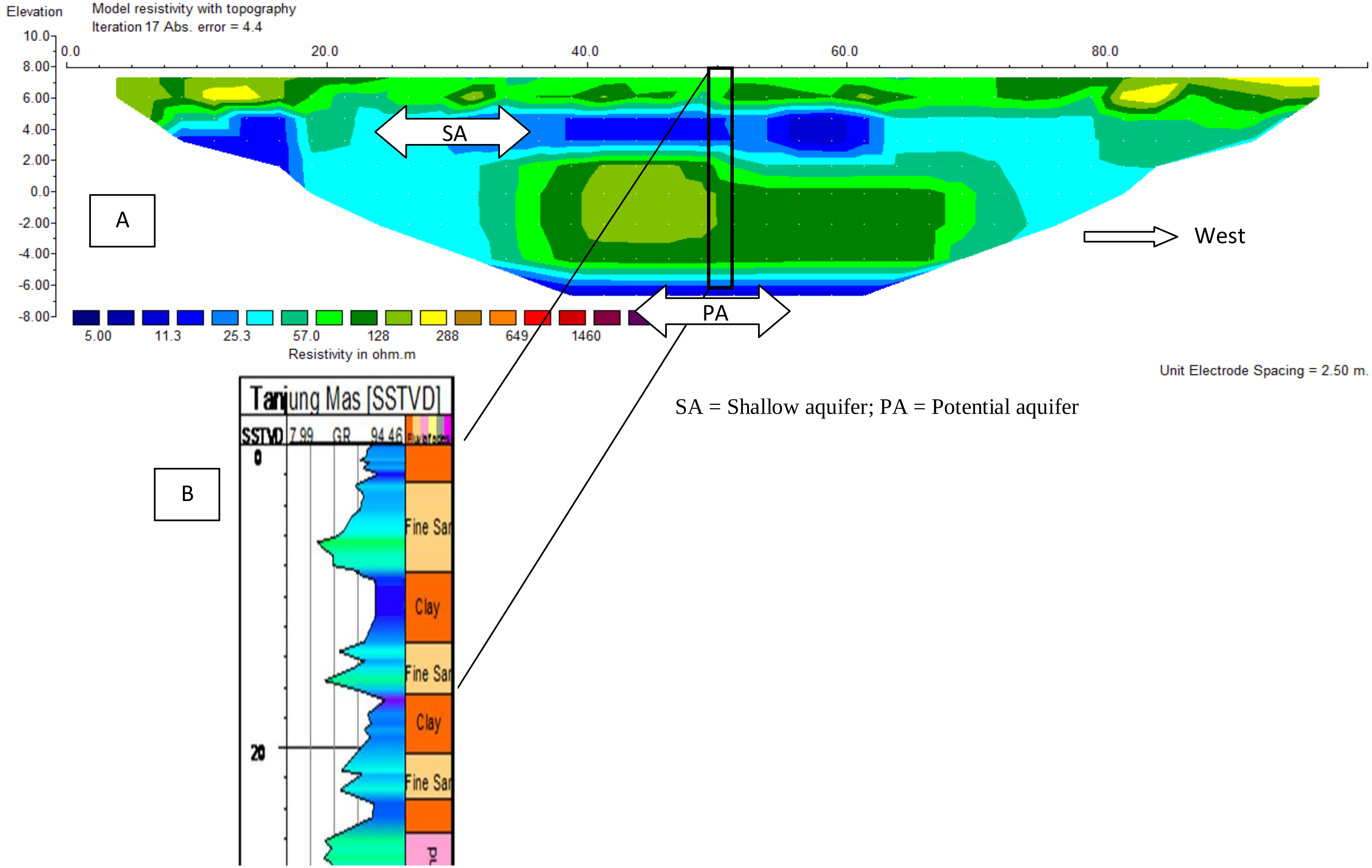
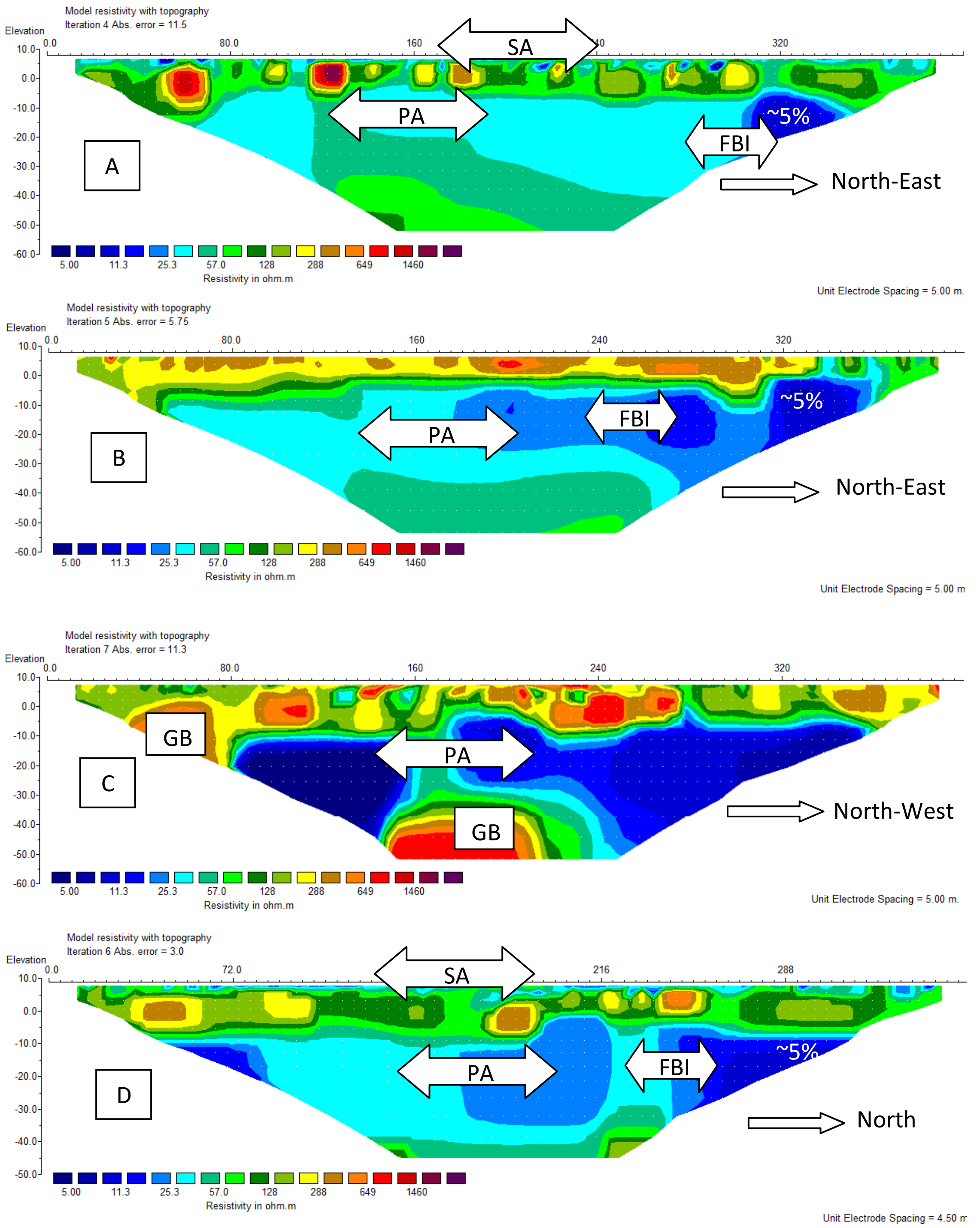


Figure 6.10. (A) Geoelectrical model for Tanjung Mas, (B) Subsurface lithology of Tanjung Mas derived from gamma ray interpretation.

The survey site for line A301A, A301B, A301C and A301D were located near a drainage system with an elevation of around 8 to 9 m above mean sea level. Unfortunately, no groundwater samples were collected with the absence of well around the site. The geoelectrical model of line A301A, line A301B, line A301C and line A301D are shown in Figure 6.11.

In the geoelectrical model of line A301A (Figure 6.11.A), a relatively low resistivity value (30-50 ohm.m) is observed near the surface extending to a depth of about 2 m. This corresponds to the top (shallow) aquifer. Alternation of less porous and porous material are revealed at the depth 2 to -4 m that is indicated by the occurrence of a relatively high (~120 ohm.m) and a low (~80 ohm.m) resistivity value respectively. The relatively lower resistivity value (~20 ohm.m) is observed in the zone with the depth of -6 m to -25 m. This indicates the presence of a less compacted and more porous material such as porous sand in that depth interval. This is also supported by the occurrence of sand formation based on the gamma ray interpretation in Tanjung Mas well station. Indication of the presence of brackish water (~5% of saltwater mixture) was observed at the northeast.

The line A301B is the nearest geoelectrical survey to the Kelantan River in Area 3 (see Figure 6.8). In the geoelectrical model along line A301B (Figure 6.11.B), there is no indication of shallow aquifer observed in line A301A. It is indicated by relatively higher average resistivity value of around 300 ohm.m from near surface to a depth of -4 m. The relatively lower resistivity value (10-30 ohm.m) is observed at a depth 12 - 39 m, corresponding to the potential aquifer. The brackish (~5% saltwater) and fresh water boundary is very clearly observed and occurred below the 270 m marks. This is indicated by the presence of lower resistivity value of less than 15 ohm.m at depth of around 18 m on the northeastern side and increase to the southwest side (Kelantan River ward).



SA = shallow aquifer; PA = Potential aquifer; FBI = fresh-brackish water interface; ~5% = about 5% salt fresh water mixture in aquifer; GB = Granite bedrock

Figure 6.11. Geoelectrical model of line A301A (A), line A301B (B), line A301C (C) and line A301D (D)

In the geoelectrical model along line A301C (Figure 6.11.C), relatively higher (~300 ohm.m) and lower (~200 ohm.m) resistivity value exist near surface from 100 - 270 m mark. It corresponds to more compacted material alternates with porous material with low moisture content. At around the 265 m mark, a relatively lower resistivity value (60 ohm.m) is observed near surface. In this zone surface water probably has direct contact with the aquifer. The shallow aquifer is found before 100 m mark and at several zones at depth less than 0 m. The minimum resistivity value (~5 ohm.m) is observed in the depth interval of -7 m to -32 m (in potential aquifer zone). It corresponds to brackish water with around 5% of salt water mixture and high Fe concentration (average 20 mg/L) in the aquifer system (KB 11, 12 and 13)

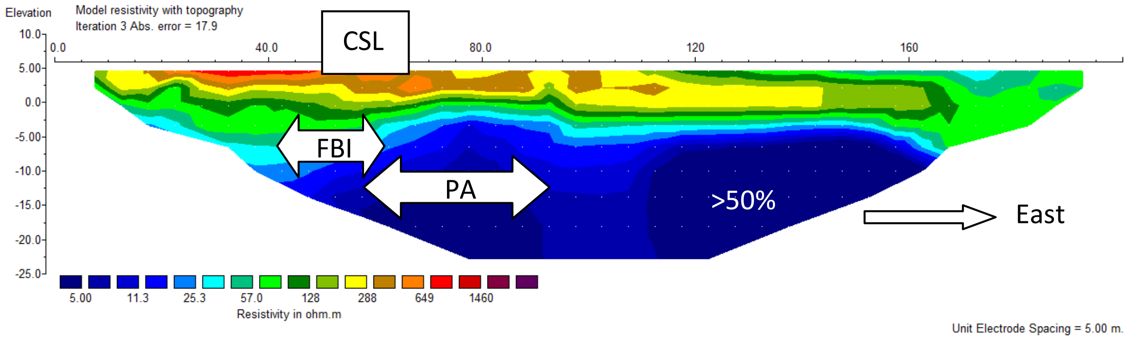
The geoelectrical model of line A301D is shown in Figure 6.11.D. A relatively lower resistivity value of around 30 ohm.m is obtained near surface to a depth of 3 m, corresponding to possibly the top (shallow) aquifer. A higher resistivity value is observed at depth deeper than 3 to -7 m. This correlates to the less porous material. In the deeper depth (16 – 40 m), the freshwater dominate at the southern zone, whilst at the northern zone of the survey line, the possibility of brackish water is observed with around 5% saltwater mixture.

Site 2

Site 2 was located around 1.4 km from the nearest beach line and around 400 m from the branch of Kelantan River to the west. The site has an elevation of 6 m above mean sea level. Due to lack of space, only one survey line (A302) was conducted in a west-east direction in the site 2.

Figure 6.12 shows the geoelectrical model of line A302. A relatively higher resistivity value (around 300 to 600 ohm.m) appears near the surface from the beginning of the survey line to 100 m mark. This value corresponds to the sandy soil with low moisture content. Whilst, relatively lower resistivity value of around 40 ohm.m can be found near surface from 120 m mark towards the end of the survey line which indicates the presence of sandy soil with higher moisture content.

At the deeper depth, up to 80 m mark, fresh water appears with resistivity value of around 20 to 60 ohm.m at the depth of 0 m (below 90 m to the end of line). Below this fresh water from depth of -6 m down, relatively lower resistivity value (<12 ohm.m) is obtained correlating to the freshwater with high percentage of salt water (>50%). It reveals dipping to the west from below 80 m mark. It is very clear the brackish is below fresh water due to brackish water has high density compared than fresh water. Unfortunately, no borehole was found at this site.



CSL = compacted soil with low moisture content; PA = Potential aquifer; >50% = more than 50% salt fresh water mixture in aquifer; FBI = Fresh-brackish water interface.

Figure 6.12. Geoelectrical model of line A302.

Site 3

The Site 3 was located around 300 m from the nearest beach line (2 m above mean sea level). Two geoelectrical resistivity surveys (A303A and A303B) were conducted. Both of the lines were almost perpendicular in orientation to each other. Electrode spacing for line A303A was at 4 m spacing of 160 m length whilst the line A303B was spaced 3 m apart for a length of 120 m with 41 electrodes. Line A303A was almost parallel to the beach line.

Figure 6.13 shows the geoelectrical model of line A303A and line A303B with two versions of their resistivity scaling due to the models have resistivity value ranging from 0.7 to 4 ohm.m. Resistivity value of around 1-3 ohm.m is observed near surface. Based on the five direct resistivity measurement, average resistivity value on the surface is 2.76 ohm.m with a standard deviation of 0.46 ohm.m. From the depth of -13 m down ward, the resistivity value is relatively higher than 4 ohm.m. This indicates the occurrence of more compacted materials such as clayey sand. The whole depth is believed to be saturated by 100% salt water.

Line A303B was conducted almost perpendicularly to the beach line and line A303A. Unfortunately both of the lines do not cross each other due to the lack of space at the site. Although the lines do not cross each other, the correlations of both lines are visually very good. At the same depth (around -13 m), both geoelectrical model show similar resistivity pattern.

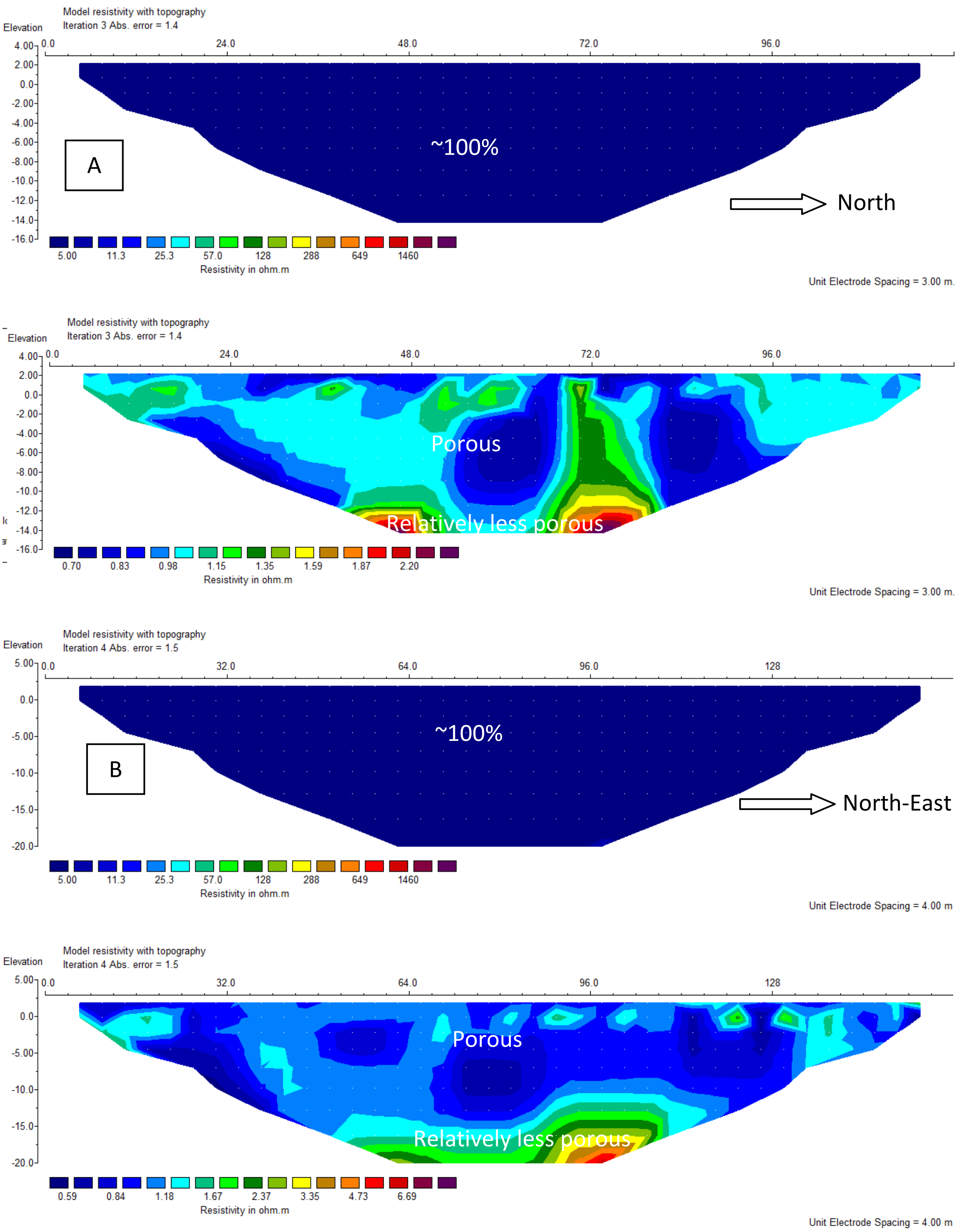


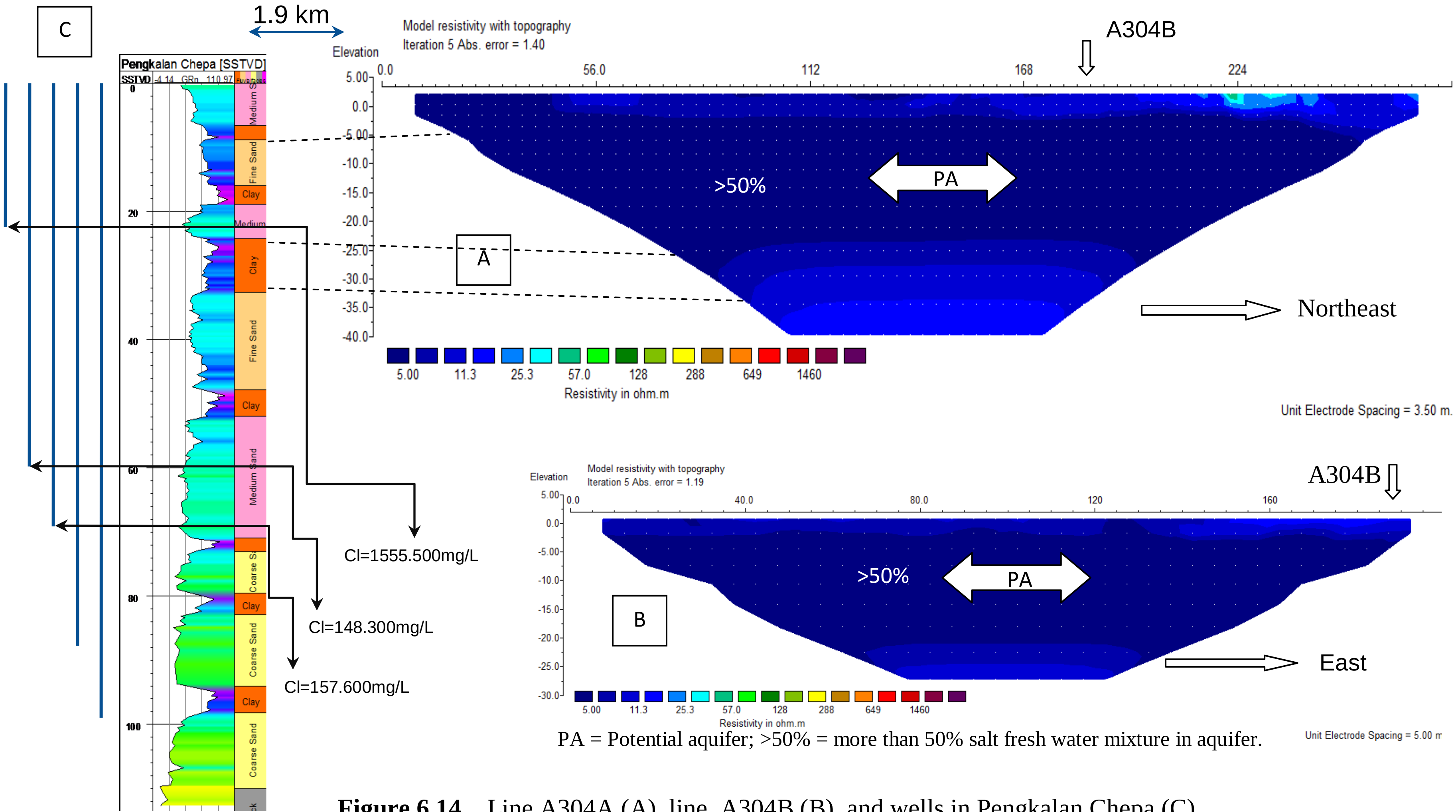
Figure 6.13. Geoelectrical model of line A303A (A) and A303B (B)

Site 4

The Site 4 was located in Pengkalan Chepa with an elevation of 2 m above mean sea level. The site was a playground and a grassing for domestic animals. The whole area was almost fully covered with their faeces (manure). The survey was conducted at the landsite with a very wet condition. At this site, two geoelectrical resistivity surveys with a different spread length were conducted (A304A and A304B). The line direction for A304A and A304B was from southwest to northeast and west to east, respectively.

Figure 6.14.A shows geoelectrical model of line A304A. A low resistivity value of around 5 – 15 ohm.m is observed near the surface, corresponding to clayey sand soil filled with faeces contaminated water. Along the position before the 150 m mark, the area was very wet, whereas after that it was relatively much drier. In the section of a depth around -5 to -19 m, a zone with a low resistivity value of around 3 ohm.m is obtained. This value corresponds to brackish water with higher concentration of salt water (>50%). Figure 6.15 shows the same line (A304A and A304B) with different resistivity scaling. In this section, it can be clearly seen that resistivity value decrease towards the sea. That means the concentration of saltwater decreases towards the landward.

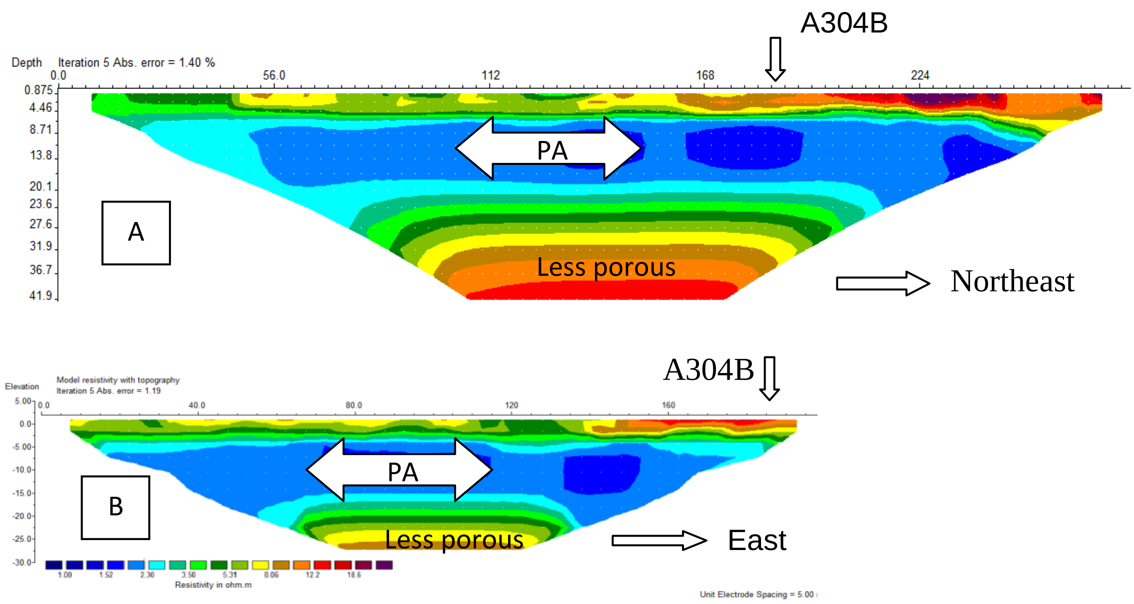
The Pengkalan Chepa pumping well station is located around 1.9 km from the survey line towards the land. At this pumping station there are five monitoring wells which named as, KB1, KB2, KB3, KB4 and KB5. Figure 6.14 shows the subsurface lithology derived from gamma ray interpretation. The sand formation that is a potential for an aquifer is found at the interval -17 to -23 m depth. The other aquifers reveal on the top. Hydrochemical data indicate high chloride content of around 1500 mg/L at the depth interval. This corresponds to brackish water with around 15% saltwater mixture. The geoelectrical model also indicate porous formation with brackish water content at this depth interval.



PA = Potential aquifer; >50% = more than 50% salt fresh water mixture in aquifer.

Figure 6.14. Line A304A (A), line A304B (B), and wells in Pengkalan Chepa (C).

The other line A304B was conducted in a west-east direction. The ending of the line A304B was at the 192.5 m mark in the line A304A. Due to the lack of space, the line cannot be conducted perpendicularly to each other in the centre position. In Figure 6.15, it can be clearly seen that the A304A line and the A304B line have a very good correlation at the crossing point. The aquifer that is filled by brackish water is also found at the same depth interval as seen in line A304B.



PA = Potential aquifer

Figure 6.15. Line A304A (A) and line A304B (B) with other scaling of resistivity value

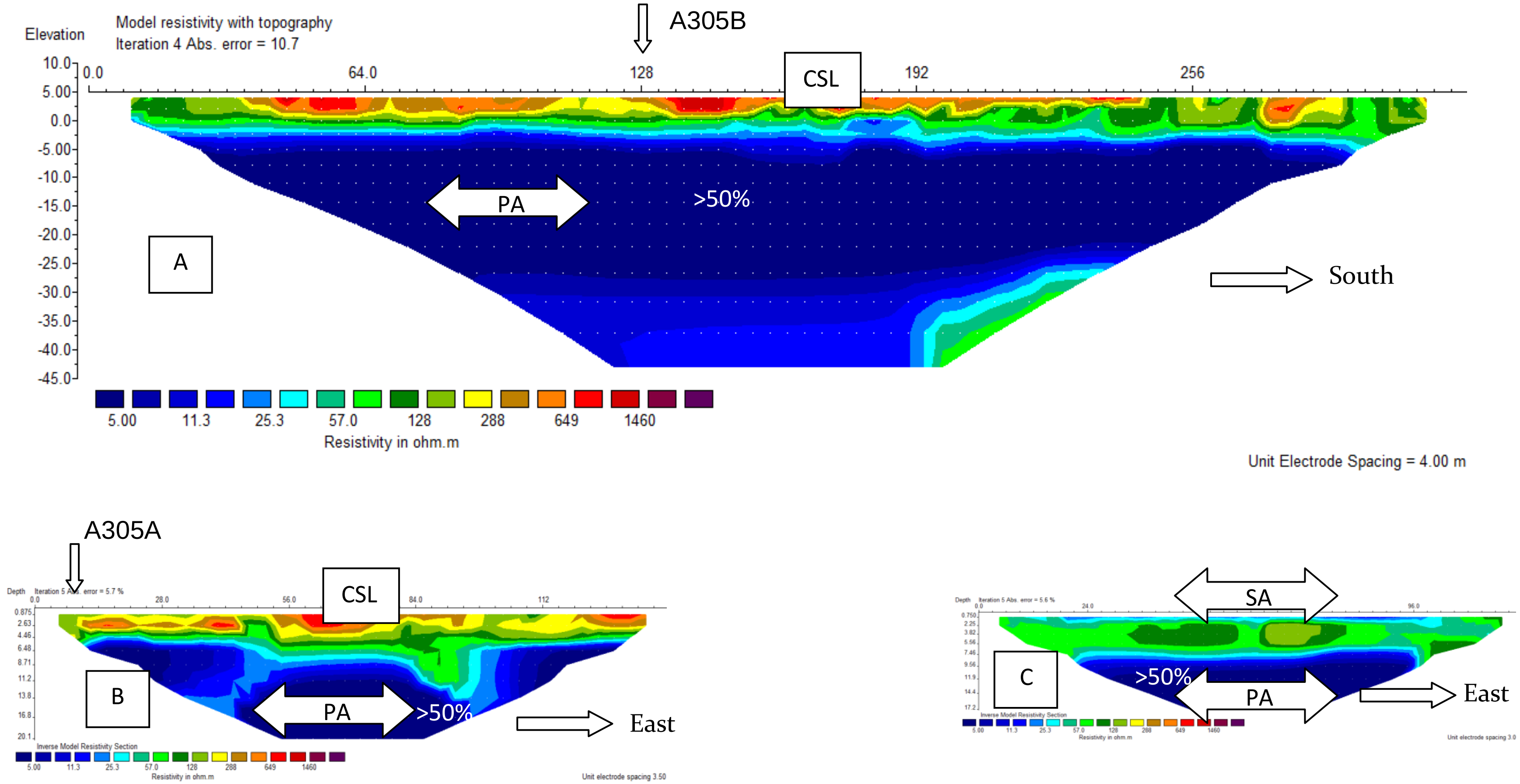
Site 5

The site 5 is situated in the northeastern part of Site1. The geoelectrical resistivity surveys (line A305A and line A305B) were conducted around 1.5 km away from the nearest beach. It was in the Polo field ground with elevation of 5 m above mean sea level. The line A305A was laid in an almost north-south direction, which is perpendicular to the postulated intrusion boundary. The line A305B was located perpendicular to line A305A at the position of 84 m mark and the position of 0 m mark for line A305B. Line A305C was conducted at around 1 km from the line A305A and A305B to the northwest. The line A305C was about the same distance from the nearest beach line as both previous lines (A305A and A305B). The line A305C was performed in between a small road and a swell with puddle of water. It has elevation of 3 m above mean sea level.

In the geoelectrical model along lines A305A and A305B, relatively higher resistivity value (around 300-500 ohm.m) is observed near surface to a depth of 4 m. This value corresponds to the more compacted soil material with low moisture content. At the next depth, the resistivity zone of around 20-80 ohm.m in the interval of 2 to -5 m depth corresponds to the fresh water. The source of fresh water is believed to be from the groundwater recharge process, which occurs directly from rainfall and from surface run-off descending from the landward area into the coconuts fields. The region of low resistivity (<15 ohm.m) is observed at the depth of -7 to -40 m, correlating to the aquifer saturated by brackish water (>50%). The low-resistivity zone corresponds to seawater intrusion from the South China Sea. At the next depth, the relatively lower and higher resistivity value boundary in the geoelectrical model along line A305A is clearly shown as a steeply dipping curve from the landward to the seaward. This boundary reflects changes of the formation. In both geoelectrical model (A305A and A305B), for the same depth position, the resistivity zone is well matched for both lines. Unfortunately, at this site there were no groundwater sample to be taken due to no well or piezometer available.

In the geoelectrical model along the line A305C (Figure 6.16.C), relatively lower resistivity value is observed near surface to a depth of 3 m. Alteration of formation happen from more porous to less porous material at the depth 3 to -2 m. Brackish water is obtained from depth of -5 m. Compared to the previous lines, this depth is about -3 m deeper due to its ground level difference of 2 m. Overall, the brackish water dips to the landward with 2 m difference of the previous lines.

There is other interesting feature that can be found in line A305C which is not found in lines A305A and A305B. The smallest resistivity value is 0.3 ohm.m in line A305C which indicates occurrence of salt water content. This line (A305C) was conducted around 1.2 km away from the river. Whilst, the smallest resistivity value for both previous lines (A305A and A305B) is 1.3 ohm.m. The lines A305A and A305B are situated around 200 m from the branch of Pangkalan Datu River. In other word, Pengkalan Datu River has a role in increasing resistivity value for lines A305A and A305B.



CSL = compacted soil with low moisture content; PA = Potential aquifer; >50% = more than 50% salt fresh water mixture in aquifer.

Figure 6.16. Geoelectrical model of line A305A (A), line A305B (B) line A305C (C)

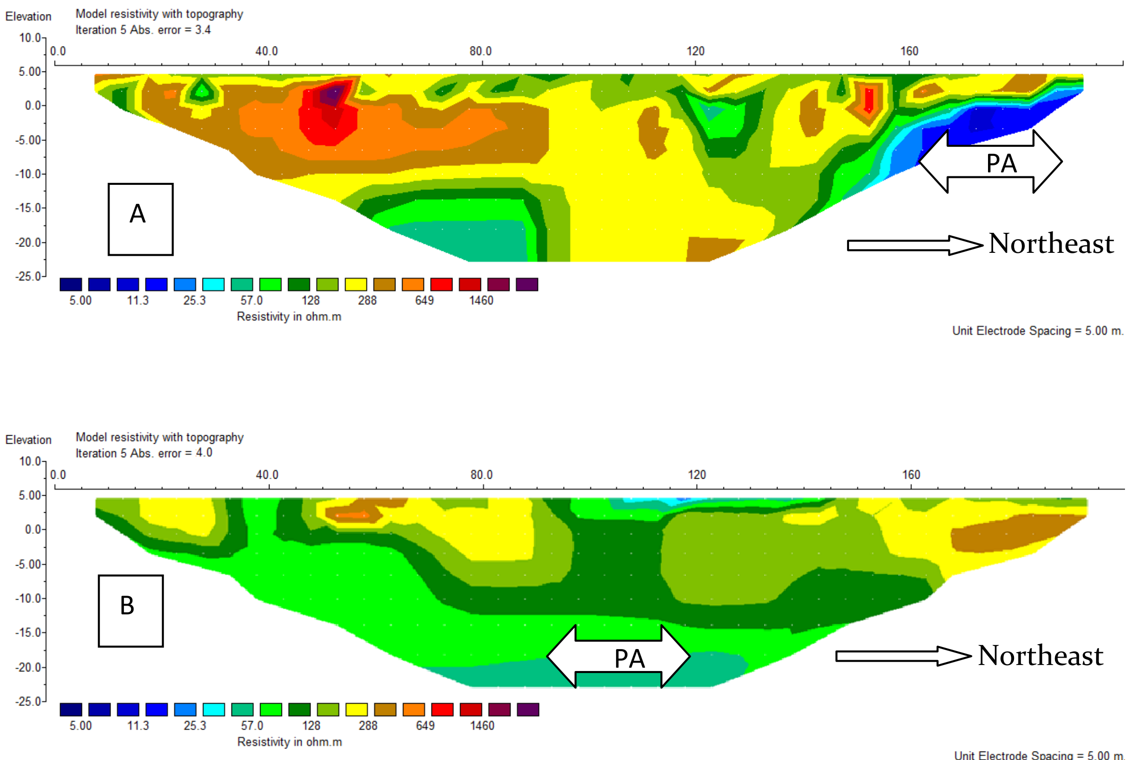
Site 6

The site 6 was located to the west of the Pengkalan Datu River with an elevation of 6 m above mean sea level. The geoelectrical survey (line A306A and line A306B) were conducted around 1 km from the river. Both of the survey lines have almost in southwest-northeast direction.

In the geoelectrical model along line A306A (Figure 6.17.A), no significant low resistivity value is observed. The lowest resistivity value is 15.2 ohm.m, which indicates the formation of freshwater to light brackish content at a depth of -6 m below 160 m mark. A relatively higher resistivity value reveal at the west side and lower resistivity value at the east side that occurs below 140 m mark. This indicates changing of the formation from less to more porous material.

The line A306B was conducted southwest to the line A306A. In the geoelectrical model along line A306B, more compacted material is still found at depth from 4 to -4 m as in the line A306A. A resistivity value of about 40 ohm.m is observed at depth -18 m downward that indicates the presence of possible potential aquifer.

Based on both geoelectrical models, no brackish water indication appeared in both sections. The brackish water probably occurs northeast to the line A306A. Unfortunately, there was no place to conduct geoelectrical survey in the northeastern part of the line and no well is found around the site.



PA = Potential aquifer

Figure 6.17. Geoelectrical model of line A306A (A) and line A306B (B).

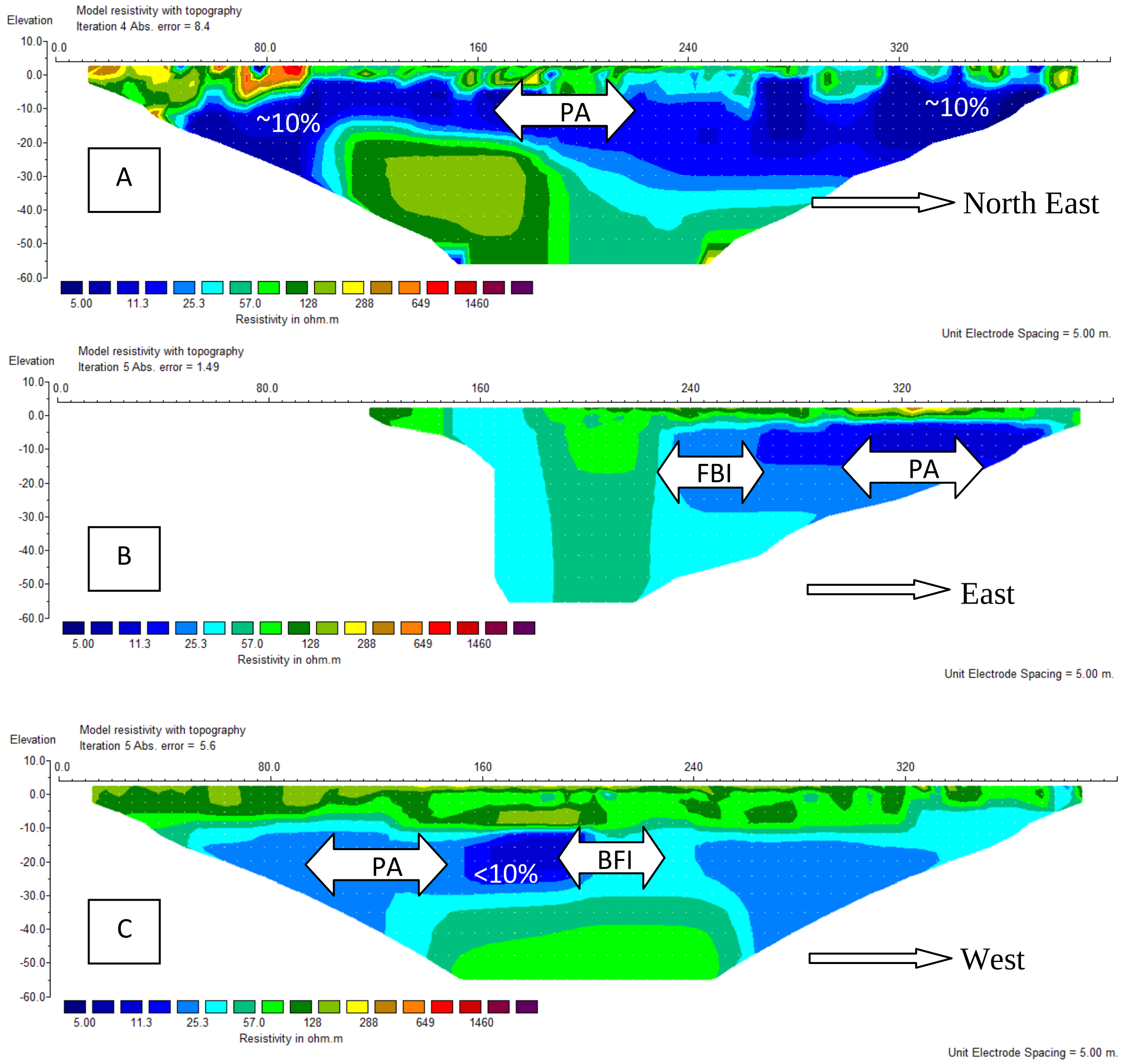
Site 7

The Site 7 is situated to the east of the Pengkalan Datu River. Three geoelectrical resistivity surveys (line A307A, line A307B and line A307C) were conducted around 7 km from the nearest beach. The lines were laid beside an artificial drainage system within a paddy field. Among the three lines, line A307A was the furthest from the Pengkalan Datu River, followed by line A307B and line A307C (see the map in Figure 6.8).

The line A307A (Figure 6.18.A) was laid in a southwest-northeast direction on the ground surface of 4 m above mean sea level. In the geoelectrical model, relatively lower resistivity value (around 16 ohm.m) is observed near surface at the 300-340 m mark. This corresponds to the more porous material. The surface water along this zone is connected directly to the shallow aquifer. At the deeper zone (-8 to -31 m), relatively lower resistivity value (8-20 ohm.m) is observed. This corresponds to the brackish water.

The geoelectrical model of line A307B is given in Figure 6.18.B. Unfortunately, data for this line was insufficient (the left half) due to some problems with the switch of the cable connector. However, the second aquifer is still found at a depth of -8 to -26 m. The low resistivity value (around 15 ohm.m) appears in the zone below the 240 m mark. In the central region of the line section, the brackish-fresh water interface is very clear imaged in this section.

The geoelectrical model of line A307C is shown in Figure 6.15.C. The line was directed towards the Pengkalan Datu River. In this section, the change of fresh water to brackish water is clearly observed at depth of -11 to -29 m. It is indicated by resistivity value of around 18.5 ohm.m on the west which is more closed to the Pengkalan Datu River. The resistivity value increase to Pengkalan Datu River, implying that freshwater concentration increases toward Pengkalan Datu River.



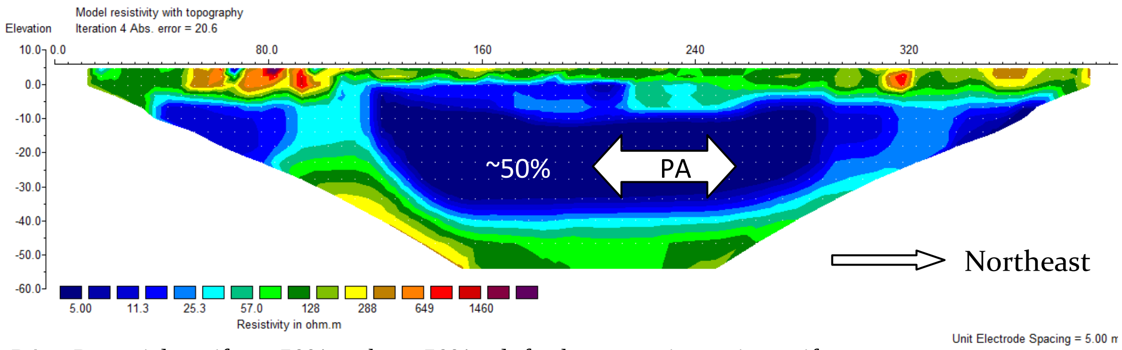
PA = Potential aquifer; BFI/FBI = Brackish-fresh/Fresh-brackish water interface.
~10% / <10% = about 10% / less than 10% salt fresh water mixture in aquifer.

Figure 6.18. (A) Geoelectrical model of line A307A, (B) line A307B, and (C) line A307C

Site 8

The northern part Kampung Tawang of around 600 m away from the beach line was chosen to locate line A308. The line direction was in an almost southwest to northeast direction. The site was 6 m above mean sea level. The survey was conducted after heavy rainfall so that the land was puddle by rainwater.

In the geoelectrical model along lines A308 (Figure 6.19), relatively lower reristivity value (100 ohm.m) appears near surface. The value corresponds to the sandy soil fully saturated by freshwater (rainwater). In the depth interval of -6 to -34 m, a low resistivity value (less than 10 ohm.m) is observed, corresponding to the brackish water (~50%). The resistivity value changes from 3 ohm.m at the northeast (nearest to the beach) to 8 ohm.m at the southwest. Unfortunately, there is no well reaches this depth at this site. The well WA305 was located at just about 160 and 270 m marks from line A308 with depth around 0 m. The water chemical results for this well (Table 6.5) indicate freshwater. This is also supported by resistivity value at this position of about 55 ohm.m in geoelectrical model.



PA = Potential aquifer; ~50% = about 50% salt fresh water mixture in aquifer.

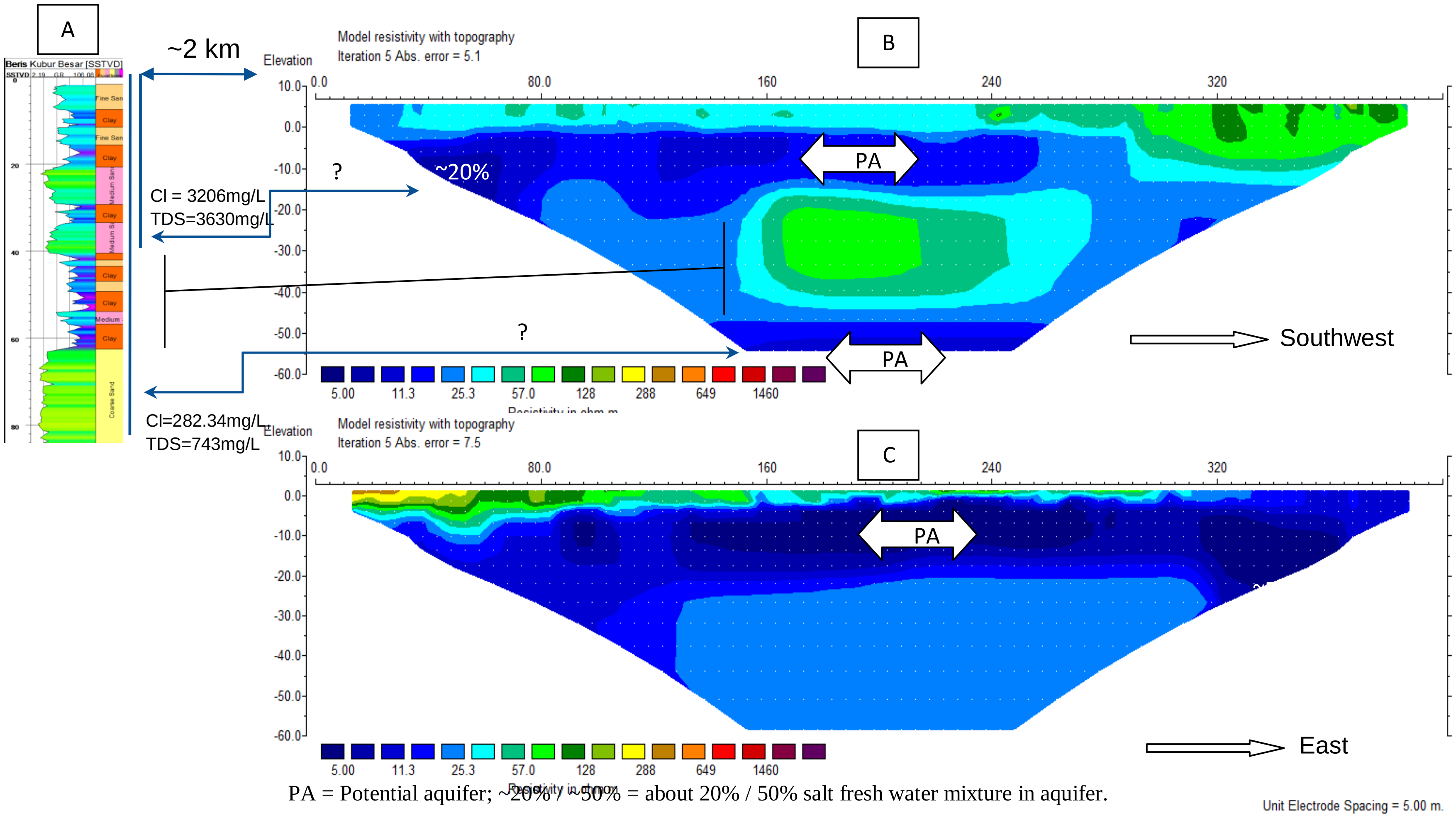
Figure 6.19. Geoelectrical model of lines A308.

Site 9

The line A309A and line A309B were located at the site surrounded by a paddy field about 6.3 km west of the beach line. Whilst the line A309B was around 1.5 km northeast to the line A309A. Both lines A309A and A309B were surveyed beside small road shoulder with an elevation of 7 m and 3 m above mean sea level, respectively.

The KB32, KB33, KB34 and KB35 wells are located around 2000 m southeast of line A309A. Although it is quite far from the survey line, the well data can probably be considered to assist subsurface resistivity interpretation. Subsurface lithology was obtained from gamma ray interpretation (Figure 6.20.A). In this figure, lower gamma ray value reveals from near surface to a depth of around 8 m corresponding to shallow aquifer. At the subsequence depth, clay (higher gamma ray) dominates from a depth of 8-12 m (-1 to -5 m) followed by fine sand from 12-17 m (-5 to -10m) depth. Second aquifer can be found from a depth of 20-40 m (-13 to -33 m). The well KB34 with a depth of 40.4 m (-33.4m) has chloride content 3630 mg/L (~20% seawater mixture). The geoelectrical model of line A309A shows minimum resistivity value of around 11 ohm.m at this depth (-5 to -28). However, the resistivity value indicates that it increases to the landward. The brackish-fresh water interface is interpreted below 260 m mark. At next depth, the third aquifer can be detected at a depth from -48 m downward with resistivity value of around 14 ohm.m. In the gamma ray interpretation, a sand formation is found at this depth which the groundwater in this formation has chloride content of 282 mg/L (~3% seawater mixture).

In the line A309B, the region of low-resistivity value (~12 ohm.m) at the same depth interval in line A309A (Figure 6.20) corresponds to the brackish water. However, in the geoelectrical model along line A309B, the layering of the formation is difficult to distinguish. This is may be due to the clay and sand formation is saturated by high concentration of seawater. Generally, in both geoelectrical models, resistivity value decreases towards landward. It indicates that the brackish water reduces to the landward.



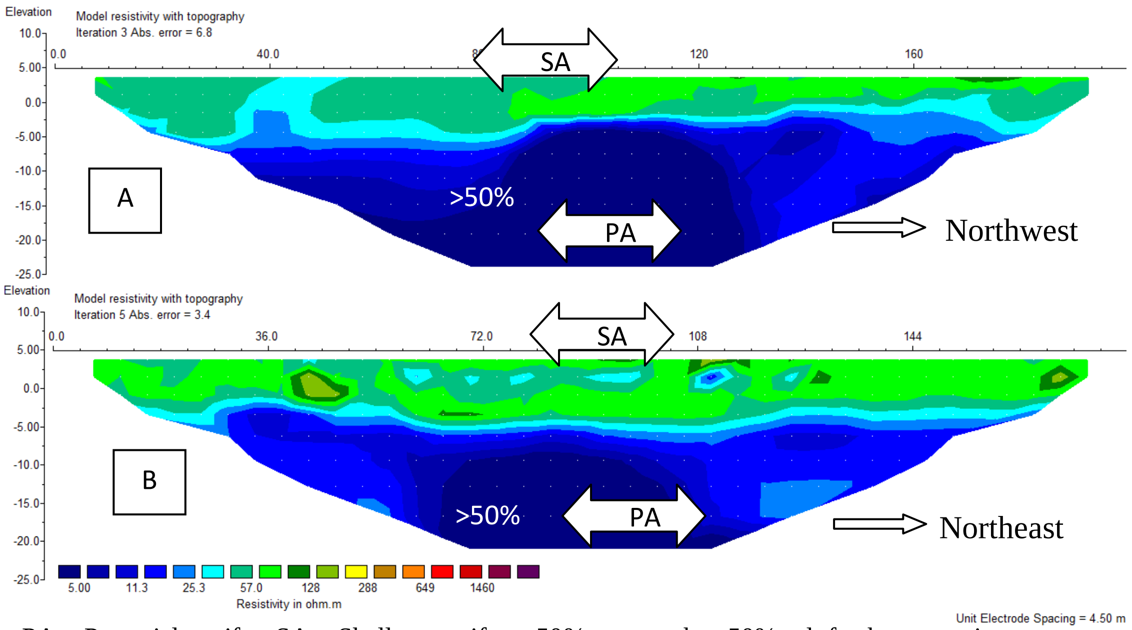
PA = Potential aquifer; ~20% / ~50% = about 20% / 50% salt fresh water mixture in aquifer.

Figure 6.20. (A) Beris Kubur Besar well, (B) Geoelectrical model of line A309A and (C) line A309B

Site 10

Site 10 was located in a tobacco plantation area with an elevation of 5 m above mean sea level. Geoelectrical survey line A310A was about 0.7 km away from the beach line and nearly parallel to it. Line A310B was separated around 0.5 km from line A308A to the southwest with almost perpendicular to the beach line.

In the geoelectrical model along line A310A and line A310B (Figure 6.21), an average resistivity value of about 50 ohm.m is observed near surface. This value corresponds to the fine sand with a moderately moisture content. Relatively lower resistivity value (~15 ohm.m) is obtained from a depth of around -4.3 m downward correlate to the brackish water. Whilst, in the line A310B, it appears starting from a depth of around -10 m. In the both geoelectrical models, concentration of brackish water decreases to the landward. This is clearly indicated by increasing of resistivity value in the line A310B. Overall, at this site, brackish water dips to the landward. Unfortunately, there was no well found within this site.



PA = Potential aquifer; SA = Shallow aquifer; >50% = more than 50% salt fresh water mixture in aquifer.

Figure 6.21. (A) Geoelectrical model of line A310A and (B) line A310B

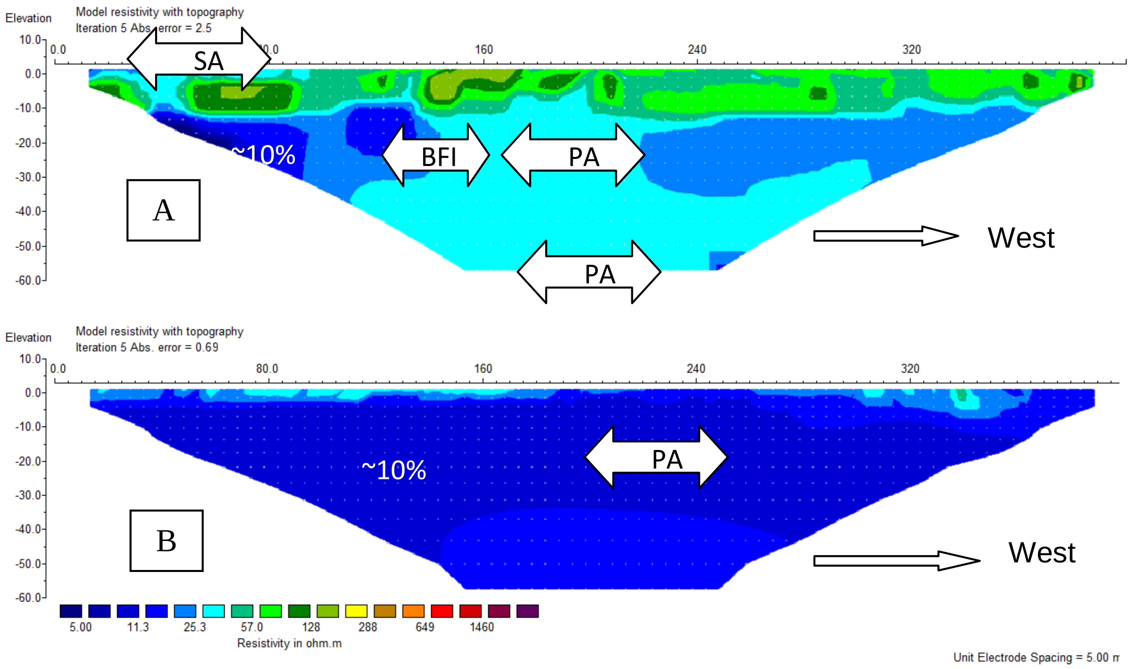
Site 11

The Site 11 was located at an area surrounded by a paddy field, 5.5 km from the nearest beach line. A puddle of water was measured around 30 cm below the ground surface. Three lines of geoelectrical resistivity survey (A311A, A311B, A311C) were conducted just next to the drainage system with an elevation of 3 m above mean sea level. The line A311A was a further line from the beach (see Figure 6.8) followed by line A311B and line A311C.

Figure 6.22 shows the geoelectrical model of line A311A and line A311B. In the geoelectrical model along line A311A, a relatively lower resistivity value (25 ohm.m) reveals from near surface to the depth of around -4 m. This value appears from the beginning line until 130 m mark, indicating occurrence of shallow sandy aquifer. A less porous material (see Table 6.1) is obtained from the depth of -4 to -12 m with resistivity of around 100 ohm.m. Alternating porous and non-porous materials occurs at this interval depth. A relatively lower resistivity value (less than 10 ohm.m) occurs from a depth of -17 to -37 m below the beginning of line and gradually increases to around 30 ohm.m until 140 m mark. The beginning of the line survey is more close to the beach line. That means, the changes of resistivity value in the aquifer imply the changes from brackish water to the fresh water.

The line (A311B) was located 760 m seaward from the line A311A. In this section the material from the surface to -9 m depth have been altered into more porous material compared to the previous line (A311A). In the zone around 20 m depth, resistivity value decreases with seaward direction. The resistivity value of 7 ohm.m is found at this depth correlating to the sand with brackish water.

The line A311C (Figure 6.23), was just around 1.3 km from the first line A311A seaward. In the section, it can be clearly seen that the change of the subsurface material from a less porous to a porous material (dark blue colour) after the 60 m mark with a depth of -1 to -7 meter. At depth below than -17 m, the resistivity value coloured dark blue (around 5 ohm.m) is definitely repossessing a more porous material that is filled with salt/brackish water. This interpretation is supported by hydrochemical data in the well around 90 m from the line towards seaward. The well data informs that at this depth ranging from 34-40 m (-31 m to -37 m), the medium sand formation filled by brackish water are obtained. This is indicated by the occurrence of high chloride and TDS content (Cl = 3206.6 mg/L TDS=3630mg/L).



PA = Potential aquifer; SA = Shallow aquifer; BFI = Brackish-fresh water interface;
~10% = about 10% salt fresh water mixture in aquifer.

Figure 6.22. (A) Geoelectrical model of line A311A and (B) line A311B

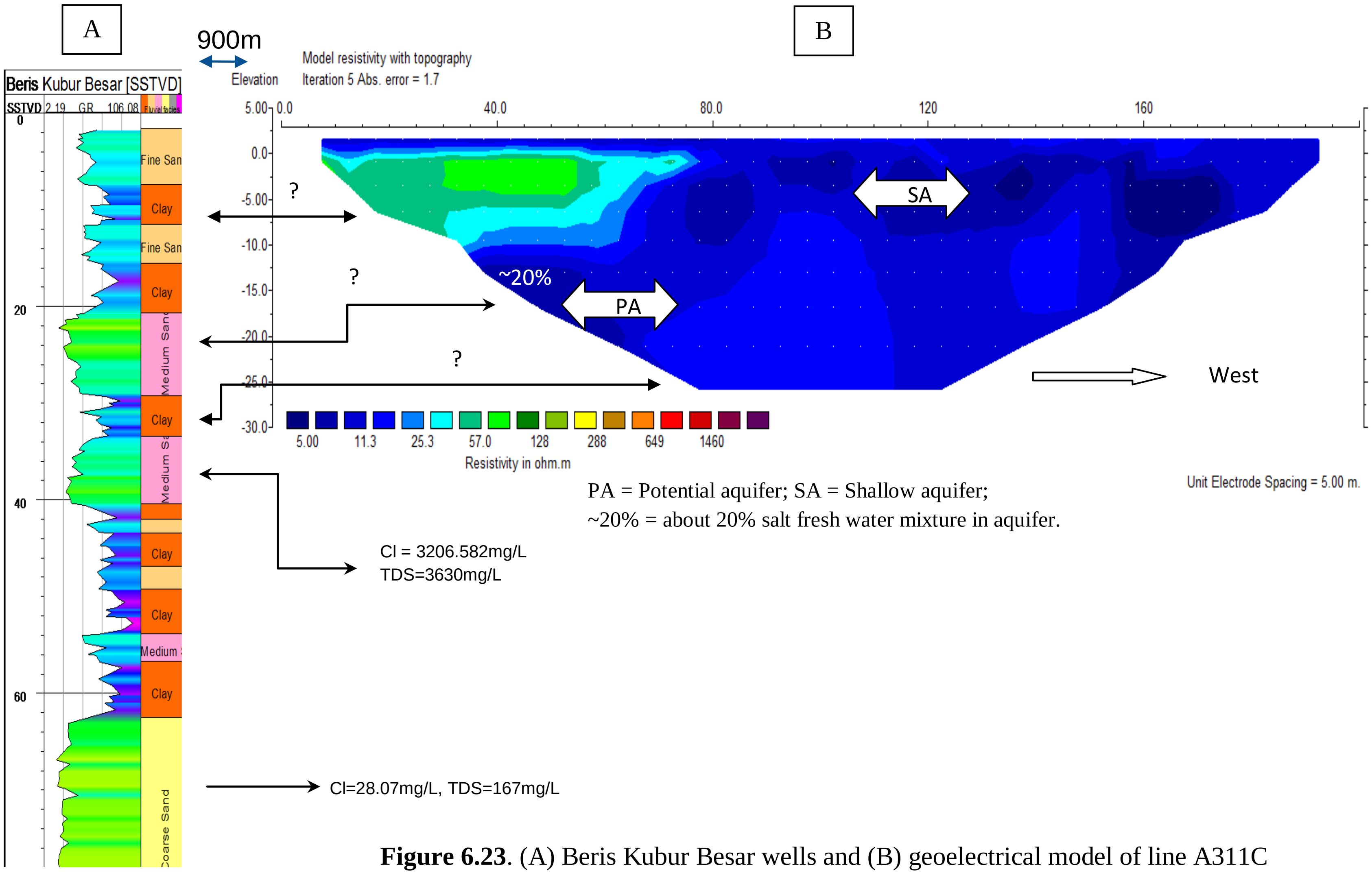


Figure 6.23. (A) Beris Kubur Besar wells and (B) geoelectrical model of line A311C

Site 12

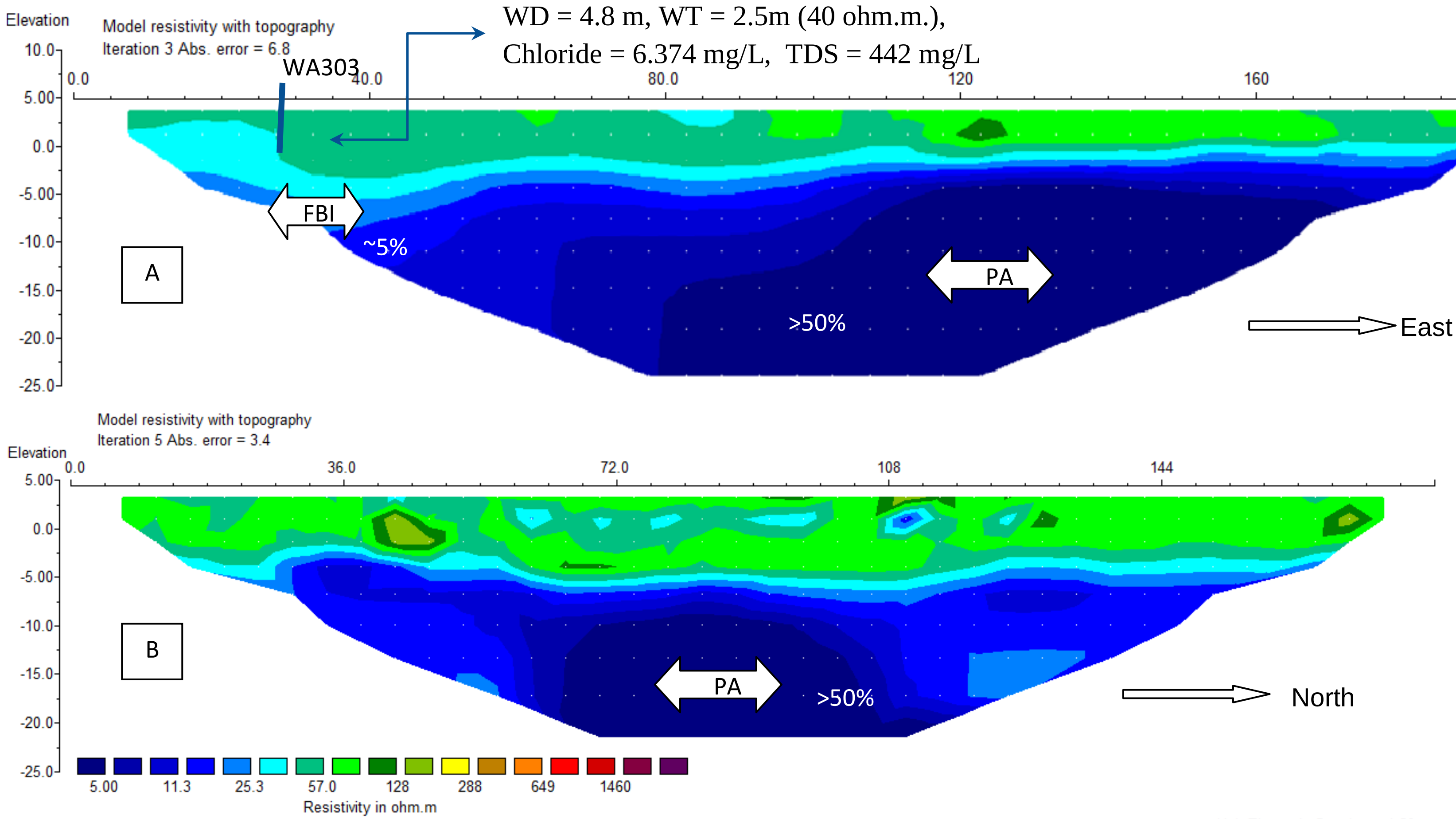
The Site 12 was located in south of Kampung Tawang. The survey lines were conducted in the marine deposited area. The reason for choosing this location was to identify the resistivity value of the brackish water within water-bearing layers in that area as well as to determine the depth boundary of the fresh-water layer that overlies the brackish-water layer.

The centre position of line A312A is about 600 m from the beach line and perpendicular to the beach line. The geoelectrical model of line A312A (Figure 6.24) shows an almost wavy interface between these two layers. The lower resistivity value of less than 4 ohm.m, which is located at around 8 m depth of the section, corresponds to the brackish water. The lower resistivity value forms a slope feature and dip to the landward. The brackish - fresh water boundary is fairly well mapped and is shown in the geoelectrical model. The fresh water layer floats on top of brackish water, since fresh water has a lower density than brackish water. This is supported by the water sample obtained from this zone (well WA303 at around 35 mark) which indicates fresh water (6.37 mg/L). The high-resistivity value of the top layer correspond to the road embankment material, because the survey line was laid out on the road shoulder (line A312A and A312B).

The location of line A312B was 1.8 km from beach line and parallel to it. In the geoelectrical model (Figure 6.24), the fresh-brackish water boundary, which shows less undulating shape, is deeper compared to the line A312A. It is very clear to recognize from the line A312A and line A312B which the dip angle of brackish-water interface increases to landward.

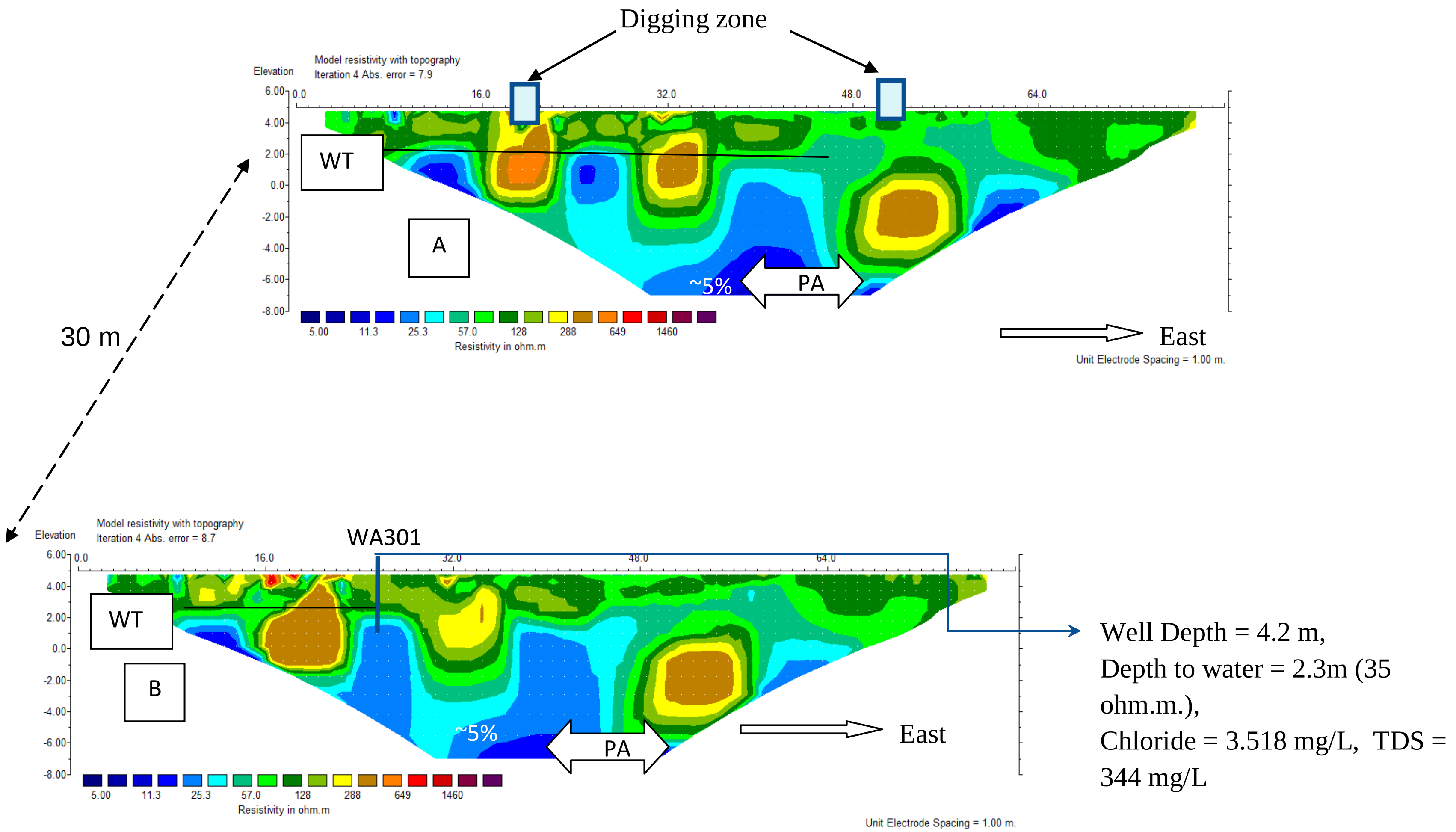
Figure 6.25 shows the geoelectrical model of line A312C and line A312D. The distance of line A312C and line A312D from the beach line was about 1.7 km. These survey lines were parallel to the beach line. In the geoelectrical model, the water table is imaged at a depth -2.7 m with resistivity value of around 35 ohm.m. Analysis of water samples (well WA301, WA302) also give fresh water indication in this zone. The well WA202 is located around 3 m from line A312C at 13 m and 60 m marks, and the well WA301 is about 1 m from line A312D at 28 m mark.

Three zones of relatively high resistivity value (above 150 ohm.m) can be clearly seen around 2 m depth, corresponds to very compacted clay material. Low resistivity value appears between them. The soil was dug in the zone of high and low resistivity value respectively (Figure 6.26). In order to know their hydraulic conductivity values, inverse auger method was employed as well. A hydraulic conductivity value of high resistivity zone is 0.0070333 cm/s, and for zone of low resistivity value is 0.0072663 cm/s. The four other lines parallel to the line A312C have been conducted at interval every 8 m from the line A312C. These lines reveal almost the same pattern and shape with line A312C, which mean, the compact clay material is formed parallel to the beach line.



PA = Potential aquifer; >50% = more than 50% salt fresh water mixture in aquifer; FBI = Fresh brackish water interface

Figure 6.24. (A) Geoelectrical model of line A312A (600 m from the beach line and perpendicular to it). (B) Line A312B (1.8 km the beach line and was parallel to it).



PA = Potential aquifer; ~5% = about 5% salt fresh water mixture in aquifer; WT = Water table

Figure 6.25. (A) Geoelectrical model of line A312C and (B) line A312D.

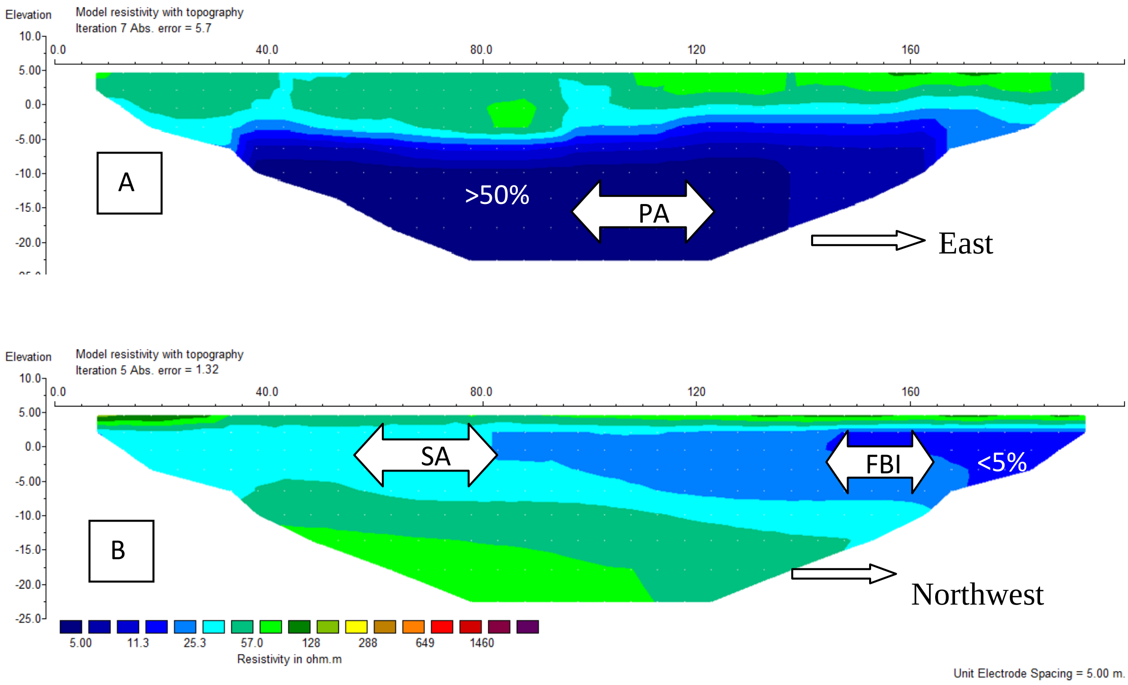
Figure 6.26. (A) Digging zone in Figure 6.25. (B) A view around Site 10.

Site 13

North of Kampung Tualang Salak was used to conduct lines A313A and A313B. The site was around 4300 m from the beach line which was a marine deposited margin. The both lines direction were perpendicular to the beach line. The lines were conducted on the road shoulder with an elevation of 6 and 4 m above mean sea level, respectively.

In the geoelectrical model along line A313A (Figure 6.27.A), relatively higher resistivity value is obtained near surface corresponding to the embankment material with low moisture content. The lower resistivity value of less than 7 ohm.m is observed starting from a depth of around -7 m down. This corresponds to sand or clay with salt/brackish water.

The line A313B was conducted at a site around 50 m from the Kemasin River. In the geoelectrical model along line A313B (Figure 6.27.B), the minimum resistivity value is around 14 ohm.m indicating low saltwater mixture (<5%). However the increases of resistivity value occur at the position near to the Kemasin River and the decreases of resistivity value occurs to the seaward.



SA = Shallow aquifer; <5% / >50% = less than 5% and more than salt fresh water mixture in aquifer

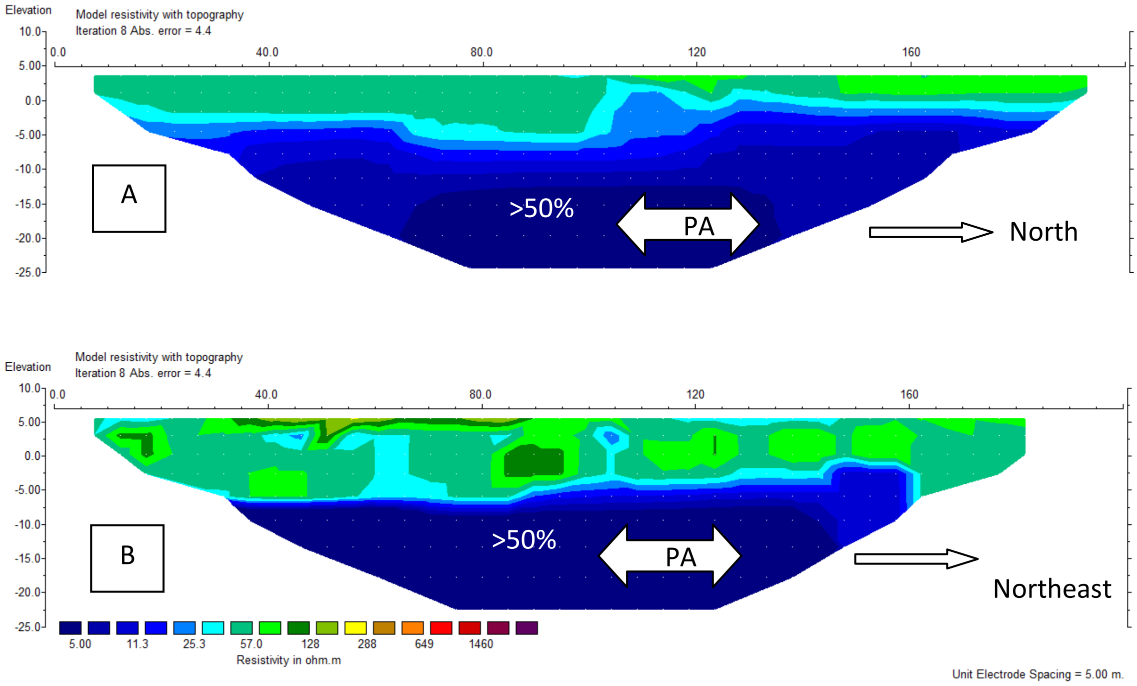
Figure 6.27. (A) Geoelectrical model of line A313A and (B) line A313B.

Site 14

The last site was located at the area of tobacco plantation in Bachok. The lines A314A and line A314B were laid about 1.3 and 1 km from the beach line respectively. Both lines were at 6 m above mean sea level.

In the geoelectrical model of line A314A (Figure 6.28.A), resistivity value of around 7 ohm.m coloured dark blue occur was observed from a depth of below -8 m. This corresponds to the sand with brackish water. The resistivity value increases gradually from the depth (-2 m) up to the surface as the fresh water infiltrate from the surface.

In the geoelectrical model for line A314B (Figure 6.28.B), more compacted and soft material layers alternation is clearly observed from the surface to -5 m depth. These are indicated by circular features with green in colour. At the next depth (around -5 m), the fresh-brackish water interface can be observed more clearly. The brackish water has dip plane to the landward.



PA = Potential aquifer; >50% = more than 5% salt fresh water mixture in aquifer

Figure 6.28. (A) Geoelectrical model of line A314A and (B) line A314B.

6.3.3. Salt/brackish-fresh water interface mapping

Based on interpretation of all the geoelectrical resistivity model, the possibility of salt/brackish-fresh water interface can be predicted as shown in Figure 6.29. This figure shows a contour with resistivity value of approximately 18 ohm.m in a depth interval of around 20 to 35 m from the ground surface. The brackish-fresh water interface (the blue line) can be found around 6-7 km from the nearest beach line. This result quite different with result derived by Samsudin (2007) (Figure 2.1). In the result of Samsudin (2007), the resistivity value increase to landward around the Kelantan River.

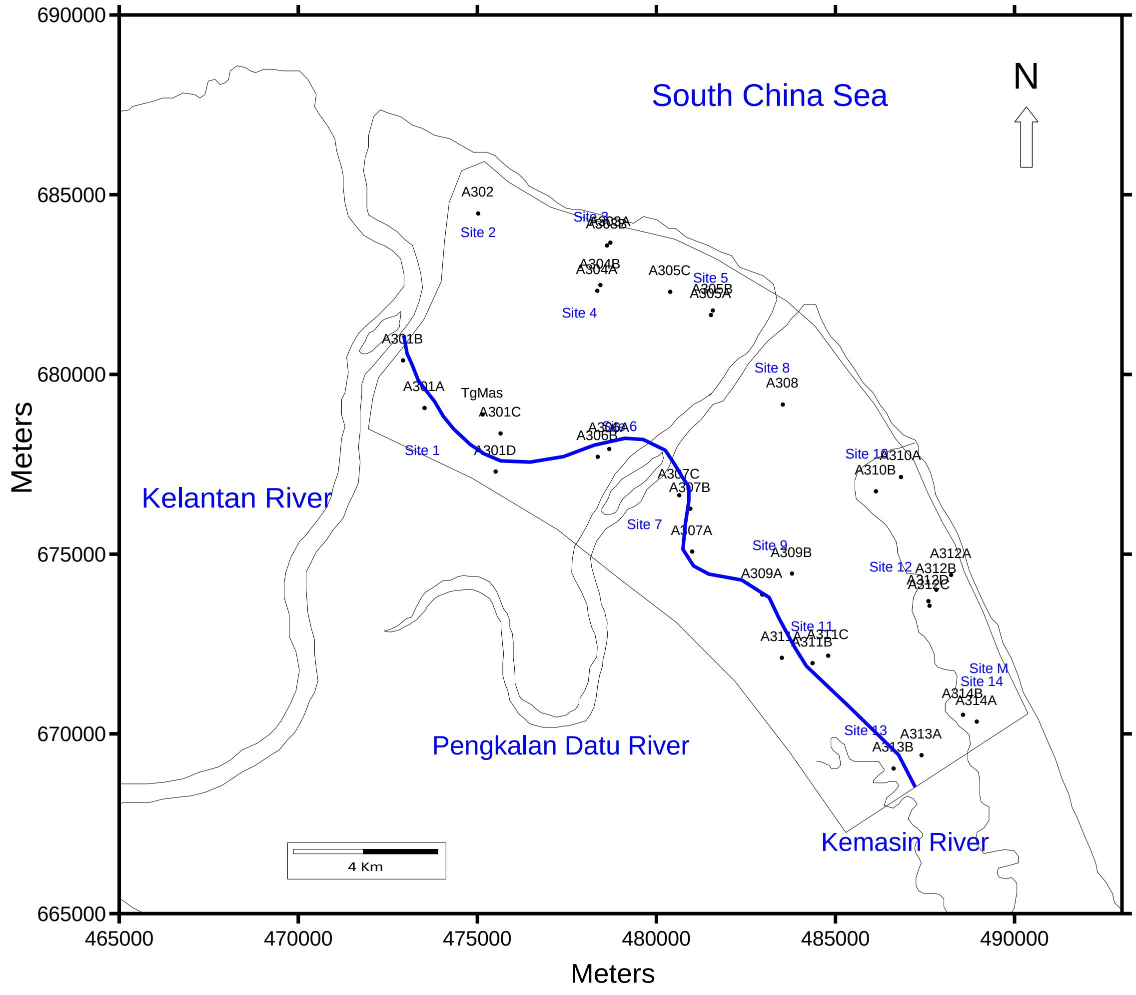


Figure 6.29. The map with a line of the salt/brackish-fresh water interface (blue line) in the interval depth of 20 to 30 meters. The map has been prepared based on geoelectrical resistivity data.

At the area around Pengkalan Datu River, the salt/brackish-freshwater interface curving toward the direction of the river flow. This indicates that there is a possibility of groundwater in the aquifer being influenced by the water of the Pengkalan Datu River. The subsurface profile around this area can be found along line A203 and line A204. In these figures, shallow aquifer and deeper aquifer is shown clearly connecting to each other. This indicate that the possibility of such aquifers were connected to each other is very high along Pengkalan Datu and Kelantan River. As mentioned in Chapter 2 (Figure 2.11), when a river meanders through the coastal plain it builds up its bed by depositing its sediment load. When the cannel shifts the sediments are left behind, the river then builds up a new bed (Noor, 1979). In Kelantan delta, the shifting of the Kelantan River has been shown by Koopman (1972).

The salt/brackish-fresh water interface (blue line in figure 6.29) is also curving toward the direction of the Kelantan River flow. The same situation also happens here, whereby water from the river force to recharge the aquifer as connected by hydraulic pressure each other. Near to the Kelantan and Pengkalan Datu River, a relatively higher resistivity value in the geoelectrical model indicates the presence of fresh groundwater in the aquifer that is influenced by the river water (Figure 6.9.B, Figure 6.14 and Figure 6.15.C). This is a great evident that shallow/first and the second aquifer are probably connected to each other.

To better show the shape and distribution of the salt/brackish water in the aquifer, a simplified depth slice of the resistivity distribution has been developed as given in Figure 6.30. The same procedure in subchapter 4.3 is used to obtain the depth slice resistivity distribution here.

Decreasing resistivity value toward the beach line in depth interval of 15-35 m is very clearly shown in Figure 6.30. This indicates that the content of seawater in the aquifer increases as more closer to the beach line. However, in the zone downward from this depth, resistivity value exhibit more than 20 ohm.m that correlates to the aquifer with fresh water content.

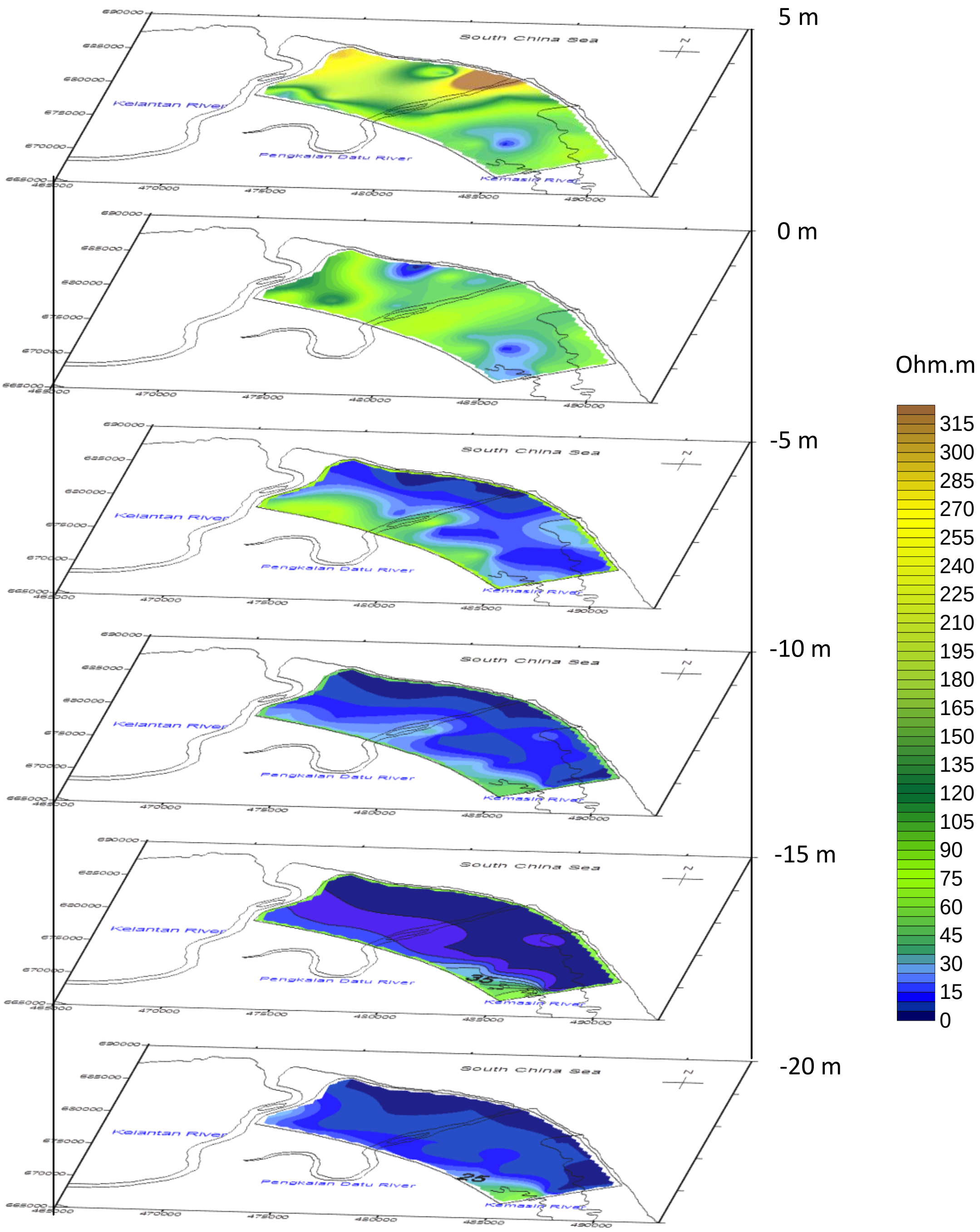


Figure 6.30. Depth slice of resistivity distribution relative to mean sea level. Relatively lower resistivity value appears from depth of -5 m to -30 m.

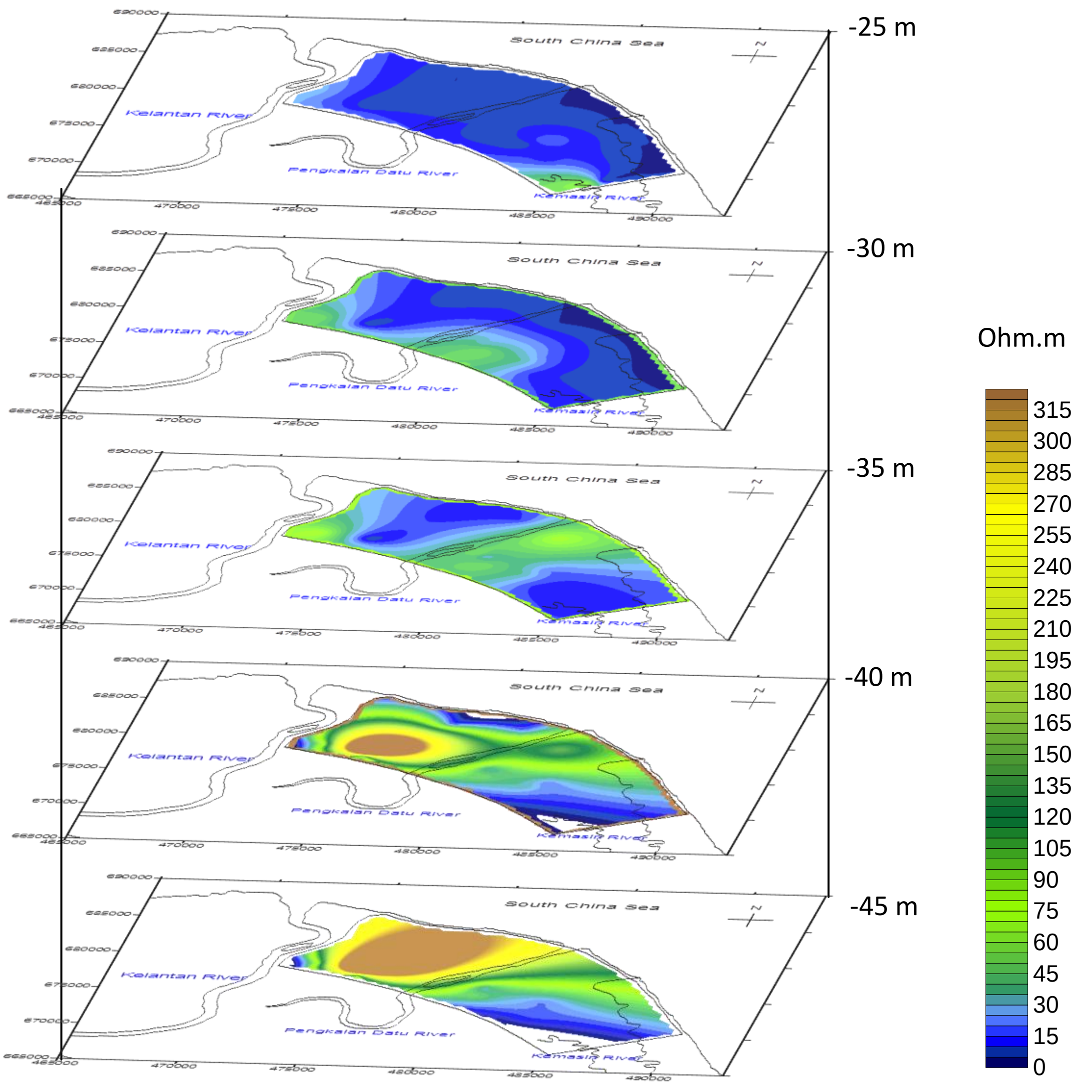


Figure 6.30. Depth slice of resistivity distribution relative to mean sea level. Relatively lower resistivity value appears from the depth of -5 m to -30 m. (Continued)

6.3.4. Coastal Aquifer

Figure 6.31 shows the base map for Area 2 and 3. In the map, the line 1 until line 7 has been prepared. These lines connect several selected geoelectrical model so that it allows developing geological model below these line based on geoelectrical resistivity interpretation. The geological models below these lines are given in Figure 6.32.

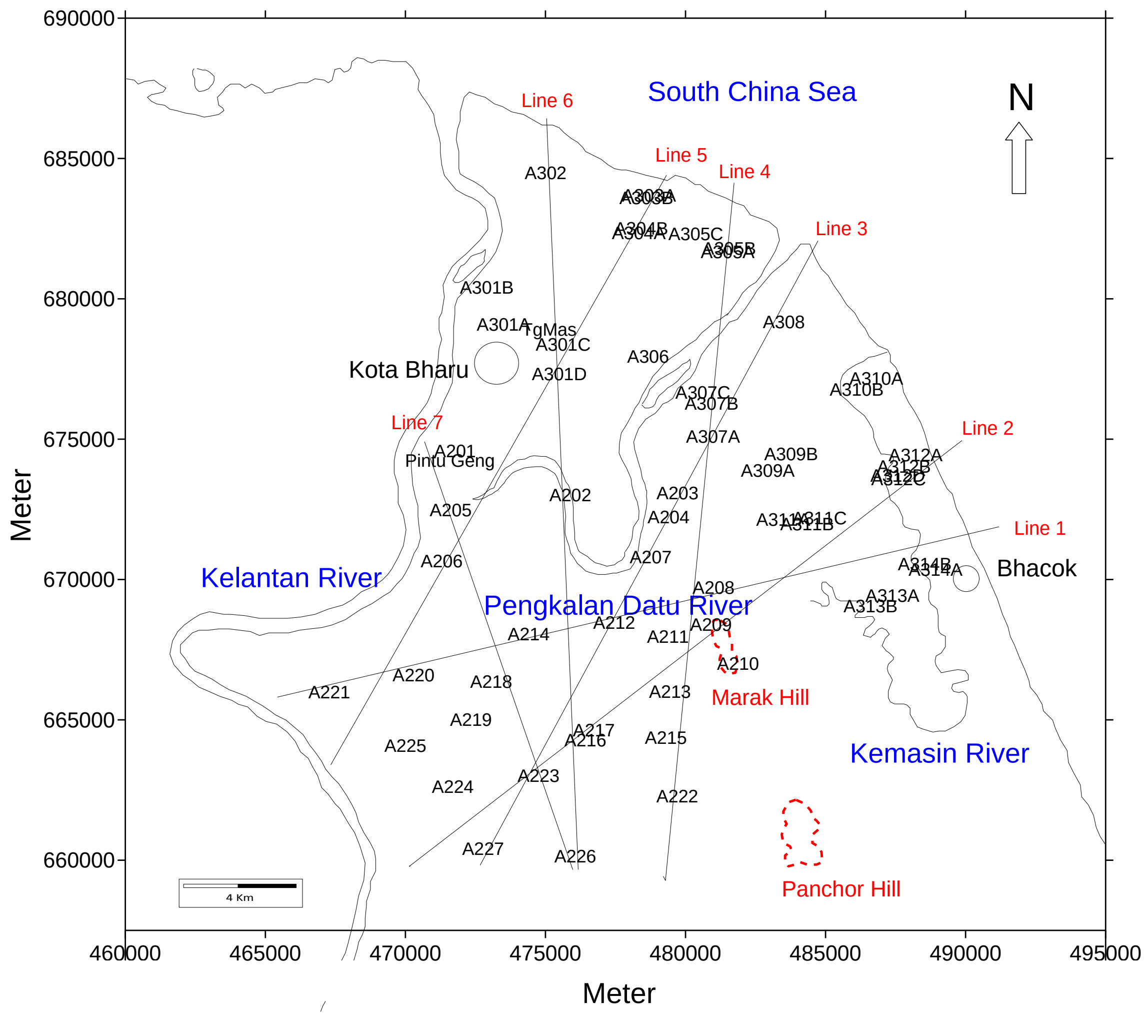
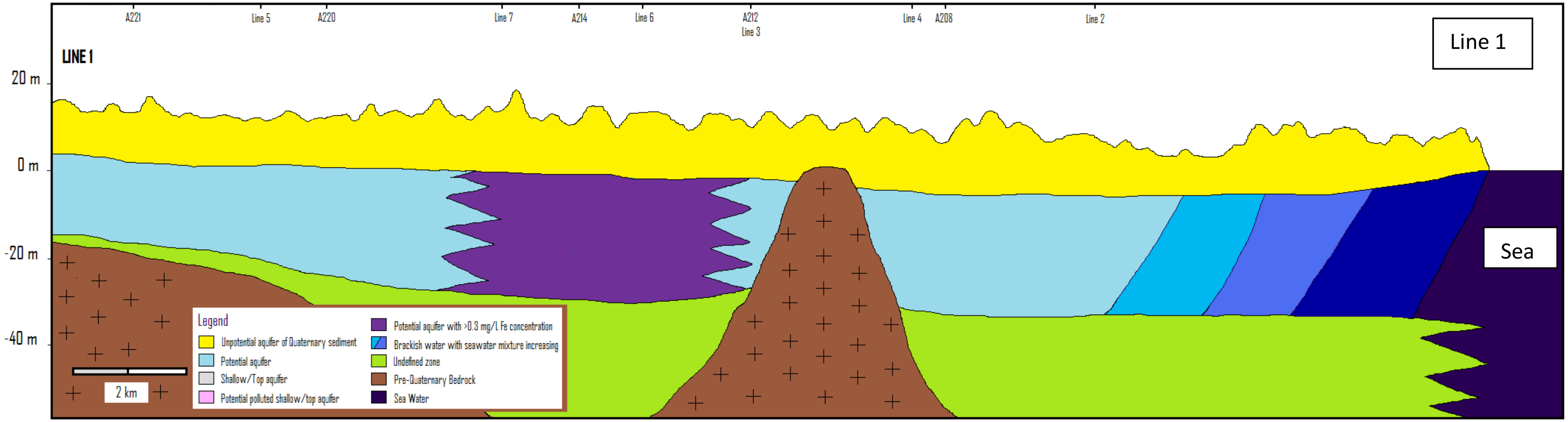
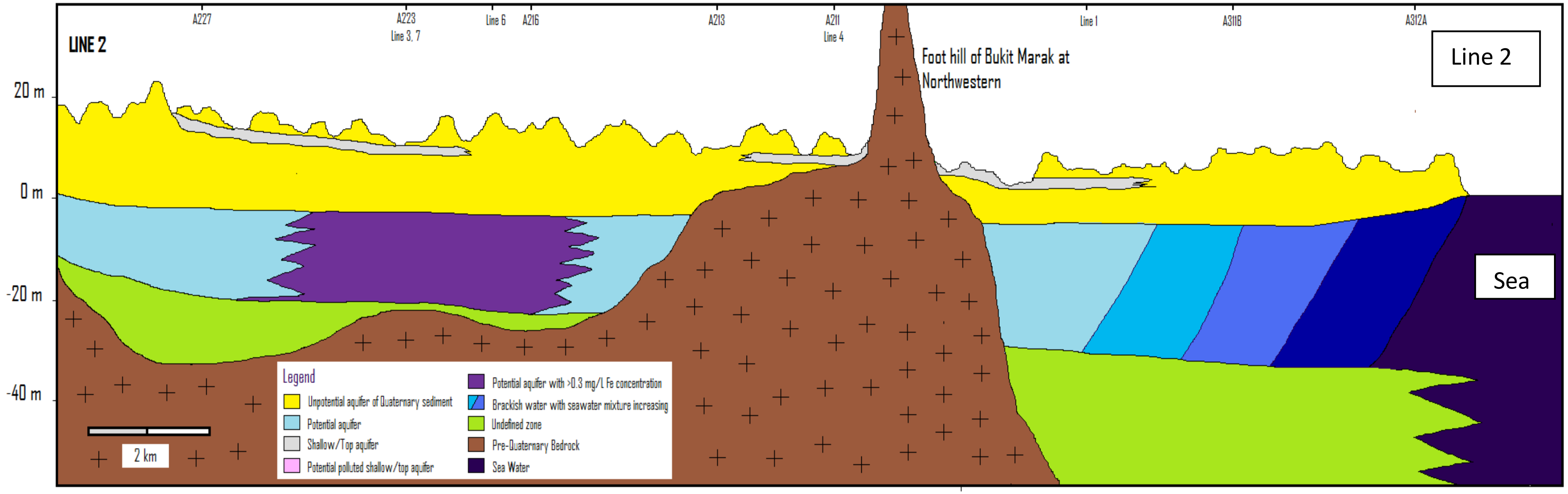
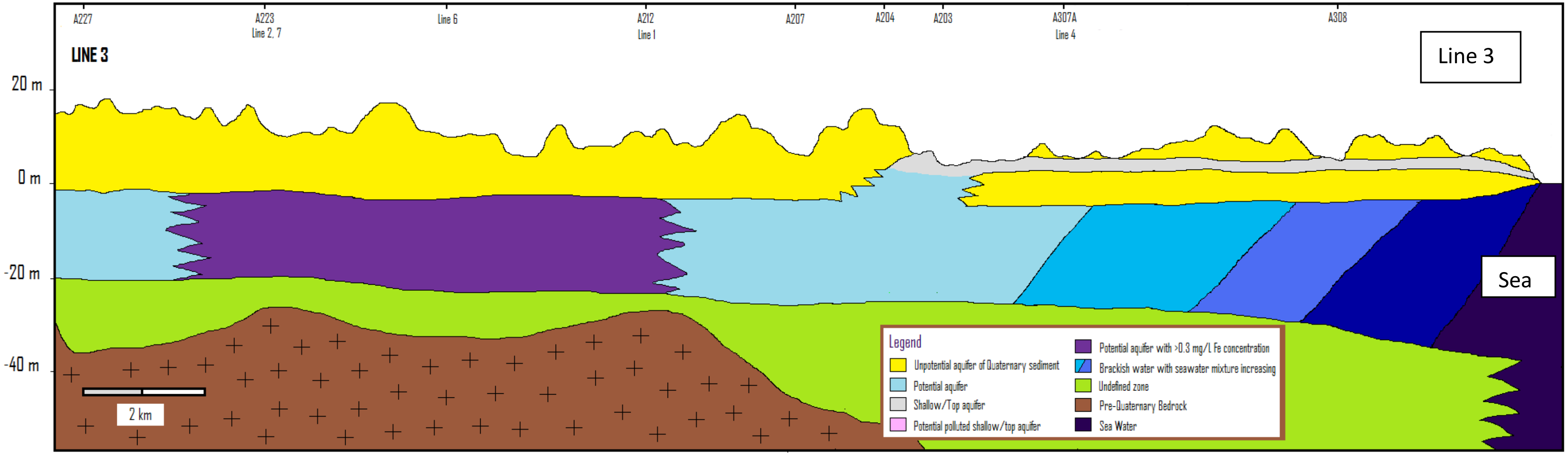
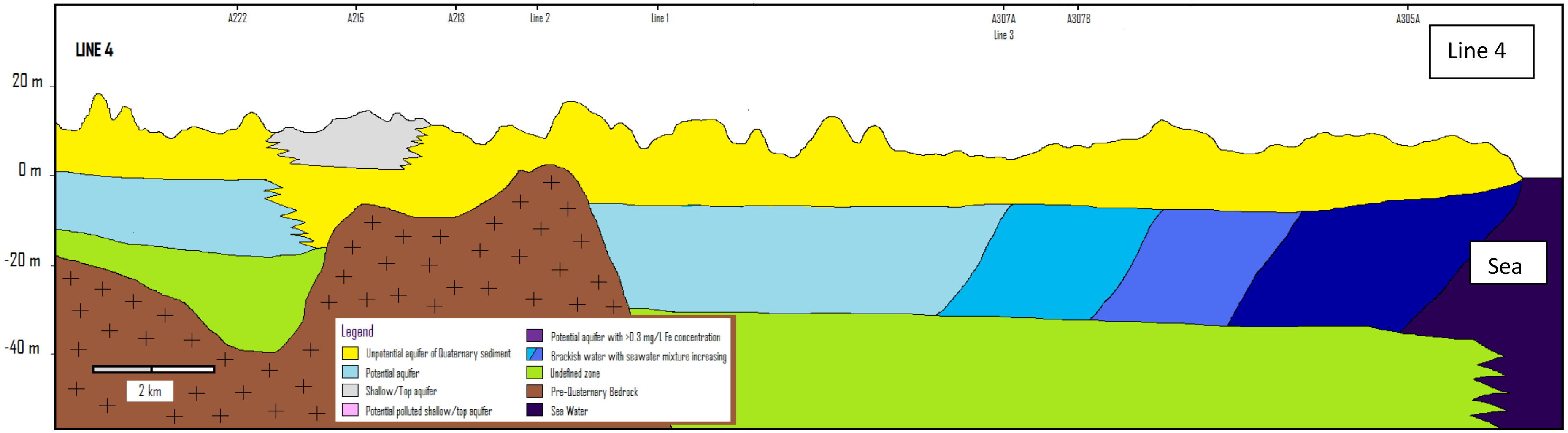


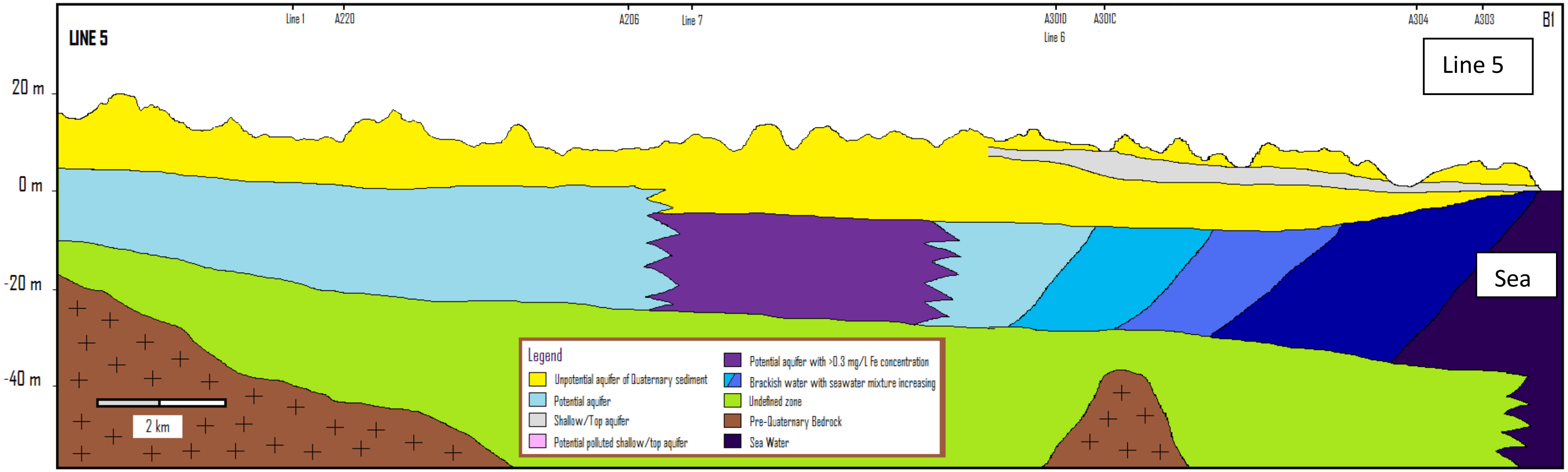
Figure 6.31. The base map for the cross section location given in Figure 6.32

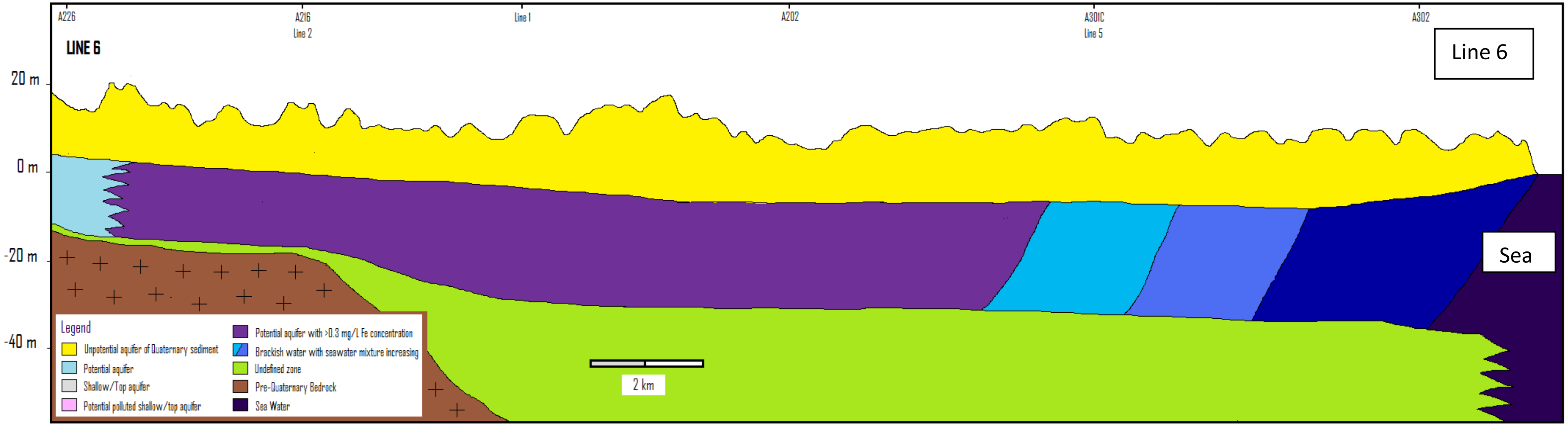

A221
Line 5
A220
Line 7
A214
Line 6
A212
Line 3
Line 4
A208
Line 2
LINE 1
Line 1
20 m
0 m
-20 m
-40 m
Sea
2 km
Legend
Unpotential aquifer of Quaternary sediment
Potential aquifer
Shallow/Top aquifer
Potential polluted shallow/top aquifer
Potential aquifer with >0.3 mg/L Fe concentration
Brackish water with seawater mixture increasing
Undefined zone
Pre-Quaternary Bedrock
Sea Water


A227
A223
Line 3, 7
Line 6
A216
A213
A211
Line 4
Line 1
A311B
A312A
LINE 2
Foot hill of Bukit Marak at
Northwestern
Line 2
20 m
0 m
-20 m
-40 m
Sea
2 km
Legend
Unpotential aquifer of Quaternary sediment
Potential aquifer
Shallow/Top aquifer
Potential polluted shallow/top aquifer
Potential aquifer with >0.3 mg/L Fe concentration
Brackish water with seawater mixture increasing
Undefined zone
Pre-Quaternary Bedrock
Sea Water


A227
A223
Line 2, 7
Line 6
A212
Line 1
A207
A204
A203
A307A
Line 4
A308
LINE 3
Line 3
20 m
0 m
-20 m
-40 m
2 km
Sea
Legend
Unpotential aquifer of Quaternary sediment
Potential aquifer
Shallow/Top aquifer
Potential polluted shallow/top aquifer
Potential aquifer with >0.3 mg/L Fe concentration
Brackish water with seawater mixture increasing
Undefined zone
Pre-Quaternary Bedrock
Sea Water


A222
A215
A213
Line 2
Line 1
A307A
Line 3
A307B
A305A
LINE 4
Line 4
20 m
0 m
-20 m
-40 m
2 km
Sea
Legend
Unpotential aquifer of Quaternary sediment
Potential aquifer
Shallow/Top aquifer
Potential polluted shallow/top aquifer
Potential aquifer with >0.3 mg/L Fe concentration
Brackish water with seawater mixture increasing
Undefined zone
Pre-Quaternary Bedrock
Sea Water


LINE 5
Line 5
Line 1
A220
A206
Line 7
Line 6
A304
A303
B1
20 m
0 m
-20 m
-40 m
Sea
2 km
Legend
Unpotential aquifer of Quaternary sediment
Potential aquifer
Shallow/Top aquifer
Potential polluted shallow/top aquifer
Potential aquifer with >0.3 mg/L Fe concentration
Brackish water with seawater mixture increasing
Undefined zone
Pre-Quaternary Bedrock
Sea Water


LINE 6
Line 6
A226
A216
Line 2
Line 1
A202
Line 5
A302
20 m
0 m
-20 m
-40 m
Sea
2 km
Legend
Unpotential aquifer of Quaternary sediment
Potential aquifer
Shallow/Top aquifer
Potential polluted shallow/top aquifer
Potential aquifer with >0.3 mg/L Fe concentration
Brackish water with seawater mixture increasing
Undefined zone
Pre-Quaternary Bedrock
Sea Water

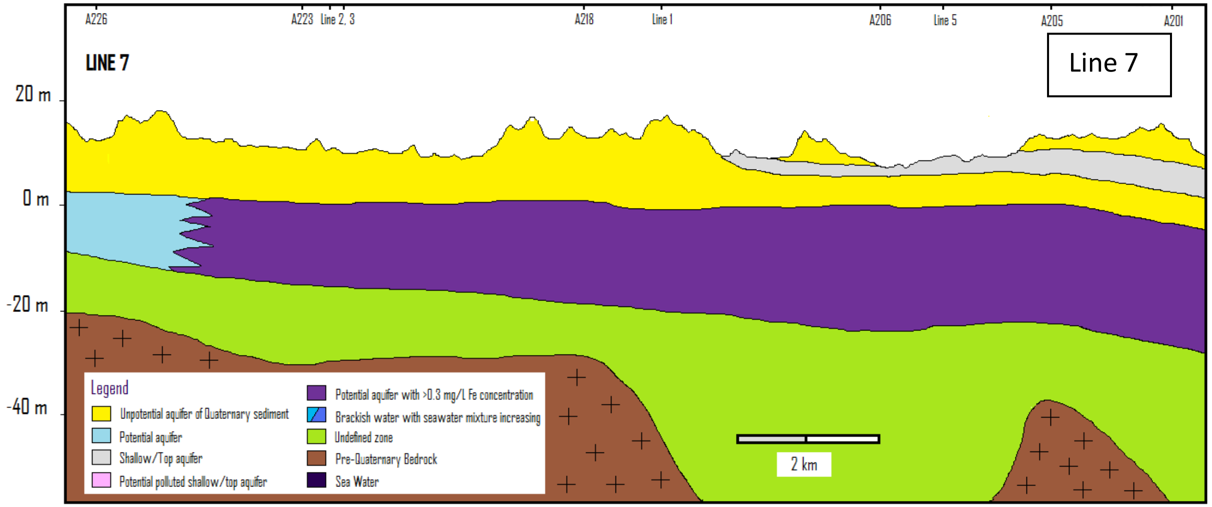


Figure 6.32. Cross section of Line 1-7. The geological models are developed based on the geoelectrical resistivity interpretation

In the profile along line 1 (Figure 6.32), the basement dips from the west to the east. However at the area around Marak hill, it is at a depth of around 10 m. From the Marak Hill to the sea, the basement cannot be detected by the resistivity survey. The same general trend is also recognized in the profile line 2 where the line crosses to the Marak Hill. In the line 3, basement is found until the left half of the line 3. The same feature trend of basement is also found in the line 4. However in the line 4, the basement can be found at the shallower depth (0 m) at the southern. In the line 5, 6 and 7, generally, basement is also found at the left half (southern) of these lines and dip to the seaward.

Shallow aquifers are found at certain location in some section. In line 3, the shallow aquifer is connected to the deeper aquifer that it occurs at the around Pengkalan Datu River. In the deeper aquifer the salt water concentration is increased to the sea ward. In the section, increasing of the salt water concentration from around 5%, 10%, 50% and 100% of seawater mixture is indicated by gradually increases of blue colour. At certain places in the land area, the purple coloured zone is indicated as the zone with high Fe concentration in the aquifer system. This zone is definitely higher Fe concentration in the groundwater.

6.4. Time Lapse Nitrate Evaluation and Monitoring in Tobacco Plantation

The same procedure of nitrate evaluation and monitoring in palm oil plantation is used in tobacco plantation area. In Bachok area, the tobacco plantation activities begin in the middle of January and ends in the middle of April every year. For the rest of the months (May – December), some farmer plants other crops such as corn, chilli, and other plantations. The plants (except tobacco) need 200 kg of urea (40% of nitrogen content) of chemical fertilizer per 1 ha during a planting period of 3 months. The fertilization scheme for tobacco is quite simple if compared to the palm oil plantation in the Area 1. The tobacco plants needs only 200 kg of fertilizer per hectare for one planting season. The fertilizer used for tobacco plants consist of the following material as shows in Table 6.6

Table 6.6. Chemical content of fertilizer for tobacco plantation (personal discussion with a field supervisor of the tobacco company)

No	Chemical	Content (%)
1	N	10.0
2	P_2O_3	2.0
3	K_2O	2.0
4	MgO	0.5
5	SiO_2	9.0
6	Ca	2.0
7	Organic Carbon	30.0
8	Moisture	20.0
9	pH	7.0 – 8.0

The nitrate concentration in the soil was investigated at different period of times especially in the site which tobacco and other crops are planted for the whole year. At this site, four geoelectrical resistivity time lapses measurement were carried out and supported by water soil chemical analysis. The first (14 Jun 2009), second (16 Jul 2009), third (03 Aug 2009) and fourth measurements (26 Sep 2009) are than referred as monitoring-1, monitoring-2, monitoring-3 and monitoring-4, respectively. One month after monitoring-4, the land where the experiment took place was replanted with a different vegetable by the land owner.

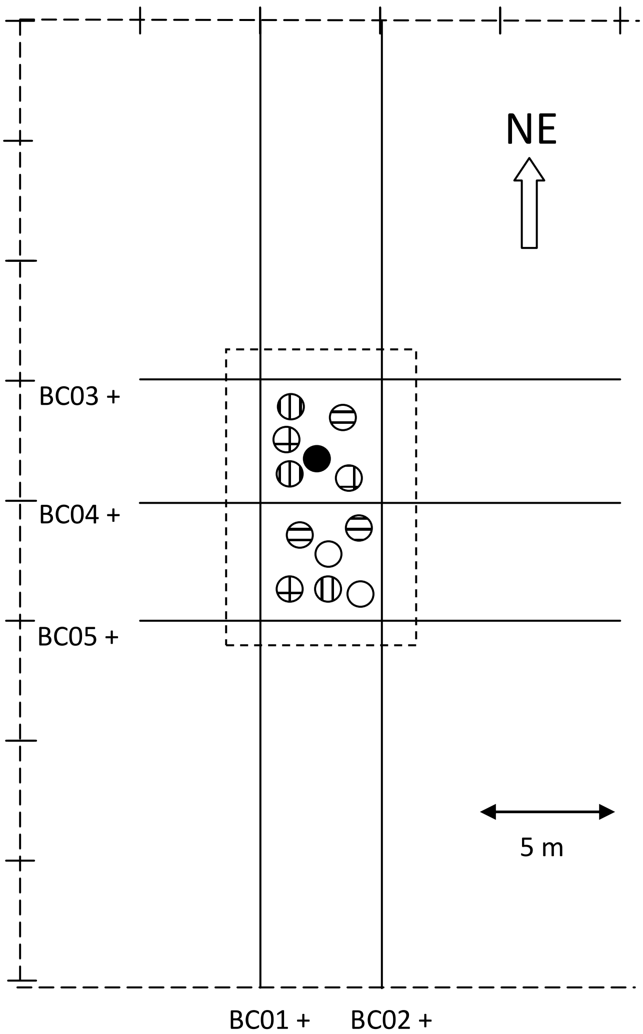
The study site is located at a former of tobacco plantation. The reason for choosing this site is because the land had not had any chemical fertilizer introduced for duration of 5 months before the survey. Around this site, relatively higher nitrate concentration has been found (WA307, in Table 6.5). The other consideration was that no permission was granted by the other farmer for fear of ruining their crops. Unlike the palm oil trees, tobacco tree is much smaller in size and very weak. The resistivity cable can easily damage the tobacco tree.

The survey specification setup is given in Figure 6.33. Soil grain size distribution and hydraulic conductivity were measured only during monitoring-1 to obtain the soil characteristics of the site. Soil samples were collected from a depth of 0 to 1 m for every 25 cm interval at the random locations. Inverse auger methods (Van Hoorn, 2007) were adapted to measure hydraulic conductivity at shallow depths above water level.

At the site, it was very difficult to dig a well using a conventional manual auger. During the digging process, soil at the side of the well wall always collapsed when the auger was moved up. That is why the monitoring well was installed only with a depth of 1 m. The depth of the water table at the site in the control well was around 80 cm every survey time.

A 1900 Soil Water Samplers (manufactured by Soilmoisture Equipment Corp, USA) were used to extract soil water at 0m, 0.25 m, 0.50 m, 0.75 m and 1 m depths for three random locations. In each sampling, less than 10 mL of soil water was obtained. The soil water samples for each depth were placed in a 40 ml plastic bottle and labelled regarding to the sampling depth. The water sample was diluted with pure water (50:50 in their composition). Subsequently, the soil's water samples were kept in plastic bottles and maintained at a temperature of 4^0C. The samples were analyzed in hydrgeochemical lab using Ion Chromatography (IC) and Inductively Coupled Plasma (ICP) two days after collecting the samples.

Two lines of 2D geoelectrical resistivity imaging surveys were performed with 0.5 m of electrode spacing with 40 m lengths for the northeast-southwest survey (Figure 6.33). Other three lines which were perpendicular to the first two lines were conducted with 20 m length due to the lack of space for the west-south direction. Each line was separated by 5 m space (Figure 6.33). At the site, it was possible to conduct gridded line surveys which have 6 lines for northeast-southwest and 9 lines for southeast-northwest, but to survey all the line will take more than one day. Thus this will lead a difference in the soil moisture contents and hence different in resistivity reading. 1.7 kg of urea (equal to 200 kg per ha) was distributed over the whole fertiliser zone after the first measurement (monitoring-1). The photograph of the site is given in Figure 6.34.



● ○ Piezometer Position and Monitoring-1
Monitoring-2
Monitoring-3
Monitoring-4
— BCXX Location of resistivity survey
Fertilizer used: Urea (200kg/Ha = 1.7kg)
Diameter of Piezometer = 4 inch
Piezometer Depth = 1 m

Figure 6.33. Field set up for evaluation and monitoring of nitrate concentration in Bachok.

Figure 6.34. View around the site survey (Top) and fertilizer introduction after monitoring-1 (Bottom).

6.4.1. Soil Properties

6.4.1.1. Soil Grain Size and Hydraulic Conductivity Characteristics

Figure 6.35 shows the soil grain size distribution for this site. Table 6.7 is a detailed grain size distribution data. Fine sand-size grain is a dominant grain. The highest percentage of fine sand is obtained at a depth of 25 cm (97%) and found in all sampling locations at the same depth. Find sand has no specific trend. Coarse sand and gravel are absent. The highest medium sand size grain (8%) is observed near surface. Silt and clay ranges from 1.98 to 3.11%. Generally, the same trend of grain size distribution occurs for all sampling location.

Figure 6.36 shows a graph of water level (ht + r/2) versus time (refer to subchapter 3.4.2). Based on the graph, the hydraulic conductivity for the site was 0.00211 cm/s. The line in the graph implies that the water level decreases with a constant rate. The hydraulic conductivity measurements were repeated for other holes to ensure better accuracy. Based on soil grain size distribution and hydraulic conductivity data, the soil condition is suitable for an aquifer and is within semi-pervious and pervious soil characters (Hillel, 1998).

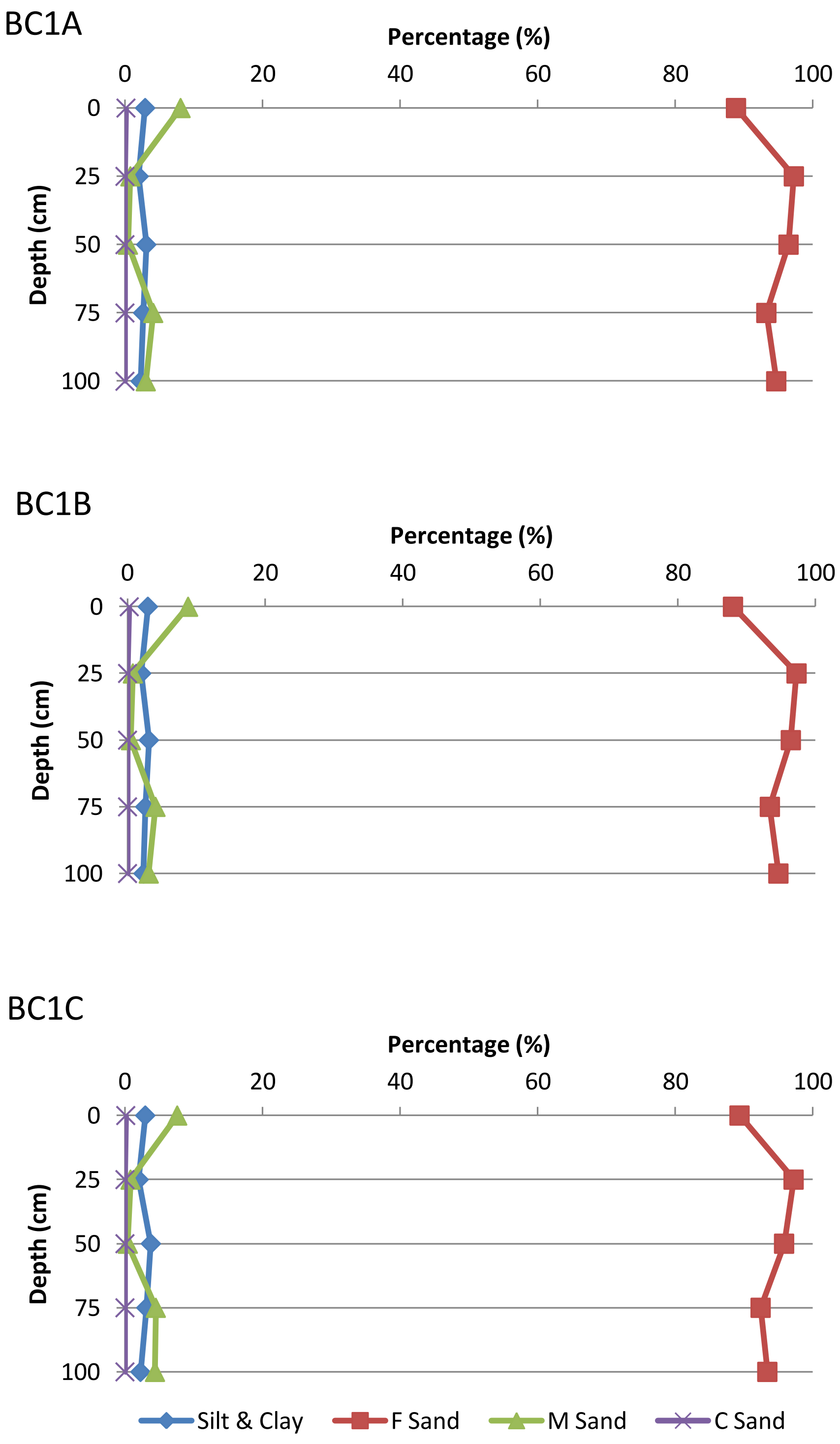


Figure 6.35. Grain size distribution with depth.

Table 6.7. Soil grain size distribution in tobacco site.

S ID	Gravel	Coarse Sand	Medium Sand	Fine Sand	Silt & Clay
	(%)	(%)	(%)	(%)	(%)
BC1a-0	0.00	0.15	8.09	88.82	2.94
BC1a-25	0.00	0.00	0.79	97.23	1.99
BC1a-50	0.00	0.00	0.44	96.46	3.10
BC1a-75	0.00	0.00	4.11	93.23	2.65
BC1a-100	0.00	0.00	3.03	94.67	2.29
Average	0.00	0.03	3.29	94.08	2.60

S ID	Gravel	Coarse Sand	Medium Sand	Fine Sand	Silt & Clay
	(%)	(%)	(%)	(%)	(%)
BC1b-0	0.00	0.25	8.80	88.00	2.95
BC1b-25	0.00	0.00	0.77	97.24	1.98
BC1b-50	0.00	0.00	0.49	96.41	3.10
BC1b-75	0.00	0.00	4.06	93.36	2.58
BC1b-100	0.00	0.00	3.08	94.60	2.33
Average	0.00	0.05	3.44	93.92	2.59

S ID	Gravel	Coarse Sand	Medium Sand	Fine Sand	Silt & Clay
	(%)	(%)	(%)	(%)	(%)
BC1c-0	0.00	0.12	7.60	89.33	2.96
BC1c-25	0.00	0.00	0.82	97.19	1.99
BC1c-50	0.00	0.00	0.42	95.81	3.77
BC1c-75	0.00	0.00	4.49	92.40	3.11
BC1c-100	0.00	0.00	4.37	93.37	2.26
Average	0.00	0.02	3.54	93.62	2.82

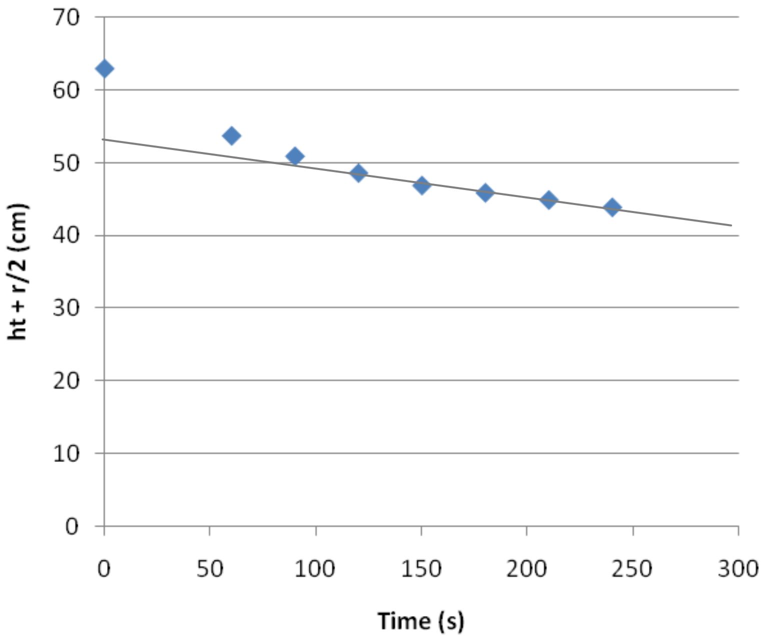


Figure 6.36. Graph of inversed auger data for determining hydraulic conductivity.

6.4.1.2. Moisture Content

Figure 6.37 shows a graph of sampling depth versus moisture content for different monitoring periods. Monitoring-1 has the highest amount of moisture content. The lowest amount of moisture content is obtained near surface and increases with depth. This similar trend is also observed in all monitoring except in monitoring-4. In monitoring-4 at depth greater than 25 cm, the moisture content do not drastically increase as in other monitoring data. This may be due to lacking heavy raining (Figure 6.38) for few day before monitoring-4. Relatively lower moisture content near surface in all monitoring is due to fine and medium sand-size grains dominate near surface. This means the soil near surface has relatively good porosity and permeability (predicted from hydraulic conductivity). Furthermore, soil moisture content was influenced by amount of rainfall and the length of time before the soil taken. Generally, the moisture content increases with depth for all monitoring.

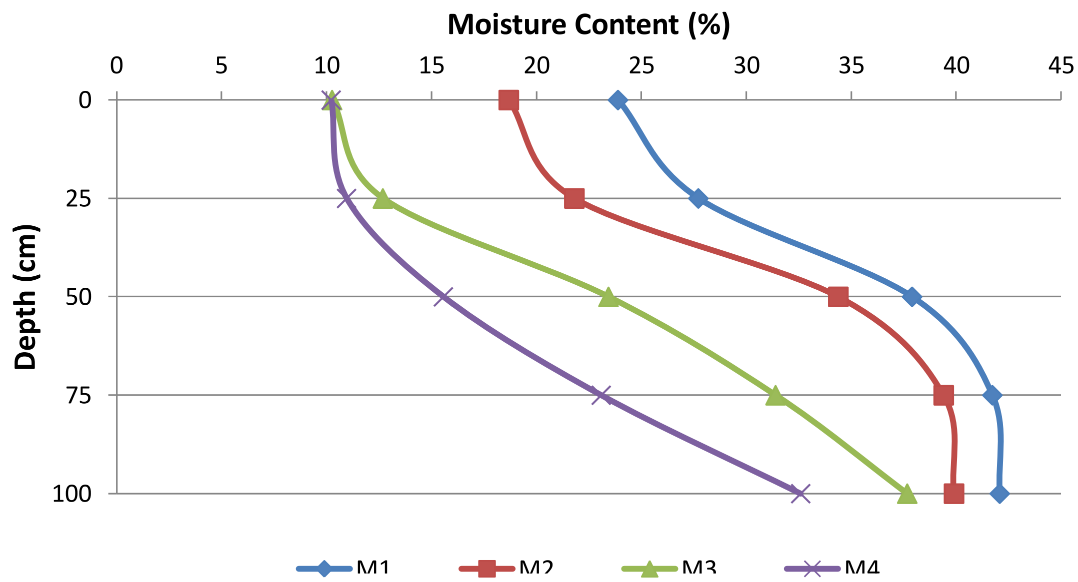


Figure 6.37. Graph of sampling depth versus moisture content for each Monitoring

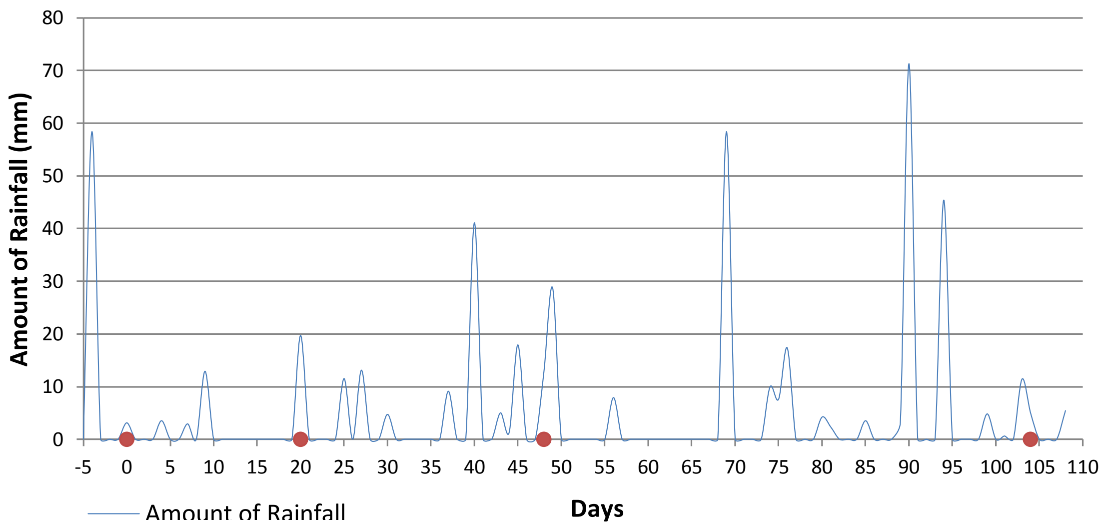


Figure 6.38. Rainfall data within survey period.

6.4.2. Extracted Soil Water Chemical Content

The chemical amounts of the extracted soil water contents for all monitoring are shown in Table 6.8. In monitoring-1, the average cation content ranges from 0 to 102.12 mg/L. The highest average cations content is Ca (102.12 mg/L) where its highest value (108.9 mg/L) is observed at depth of 75 cm. K (18.88 mg/L), Ca (102.19 mg/L), Mg (42.67 mg/L) and Na (32.40 mg/L) are the dominant cations contents among other. While Pb, Cd se Mn, Cu, Zn, Fe, As content have the average concentration less than 0.05 mg/L. The cations concentrations do not show any specific trend from near surface to a depth of 100 cm. Generally, Ca, Mg and Na increase with depth. Overall, the cation content in this site show relatively higher than cation content found in the Tok Bok site (Area 1). This is because this site being located in marine deposit environment. Residual cation content from the seawater still remains in the soil. However, all cation contents lie within the accepted limits for human consumption (WHO 1984).

For anion content in monitoring-1, the highest average anion content is chloride (25.52 mg/L) followed by sulphate (24.34 mg/L), nitrate(16.48 mg/L) and fluoride (<1 mg/L). The highest chloride concentration (31.00 mg/L) is observed at the deepest depth. The chloride concentration increases with depth. Sulphate also has the same trend with chloride. The nitrate concentration is highest near surface and decrease with depth. Fluoride has no a specific trend. Chloride and sulphate is also relatively higher than at the Tok Bok. This is also due to the residual marine deposit. Whilst, relatively higher nitrate concentration is due to animals manure that cover mostly the ground surface. However, all anion contents in the water samples lie within the accepted limits for human consumption (WHO 1984).

Table 6.8. Time lapse extracted water chemical content in tobacco site

Date	Sample ID	Chloride mg/L	Nitrate mg/L	Sulphate mg/L	Fluoride mg/L	K mg/L	Ca mg/L	Mg mg/L	Pb mg/L	Cd mg/L	Se mg/L	Al mg/L	Mn mg/L	Cu mg/L	Zn mg/L	Fe mg/L	As mg/L	Na mg/L
	BCM1-0	21.60	21.40	10.00	0.20	20.28	93.86	34.36	0.00	0.00	0.01	0.08	0.00	0.05	0.00	0.20	0.00	29.72
M-1	BCM1-25	26.80	19.80	12.80	0.00	22.46	97.52	39.10	0.02	0.00	0.01	0.00	0.01	0.04	0.00	0.00	0.00	28.44
14 Jun	BCM1-50	23.00	18.40	27.60	0.20	16.68	101.86	42.50	0.00	0.00	0.02	0.05	0.04	0.05	0.01	0.30	0.00	30.54
2009	BCM1-75	25.20	15.20	30.20	0.40	17.73	108.90	45.68	0.00	0.00	0.02	0.00	0.10	0.03	0.00	0.00	0.00	36.16
	BCM1-100	31.00	7.60	41.10	0.00	17.24	108.48	51.70	0.01	0.00	0.02	0.00	0.03	0.02	0.00	0.00	0.00	37.12
	Mean	25.52	16.48	24.34	0.16	18.88	102.12	42.67	0.01	0.00	0.01	0.03	0.04	0.04	0.00	0.10	0.00	32.40
	BCM2-0	178.00	71.00	183.60	0.20	19.26	94.82	36.52	0.06	0.00	0.01	0.08	0.03	0.14	0.03	0.20	0.00	27.96
M-2	BCM2-25	119.40	56.40	160.40	1.20	20.10	97.66	35.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	28.62
06 Jul	BCM2-50	102.40	41.60	140.80	0.60	22.38	98.20	39.96	0.00	0.00	0.04	0.03	0.06	0.03	0.00	0.00	0.00	28.50
2009	BCM2-75	97.40	26.00	132.40	0.20	20.70	105.14	42.20	0.02	0.00	0.02	0.00	0.08	0.02	0.00	0.00	0.00	33.73
	BCM2-100	96.80	23.40	132.20	0.20	19.78	103.88	49.78	0.00	0.00	0.01	0.00	0.02	0.01	0.00	0.02	0.00	37.14
	Mean	118.80	43.68	149.88	0.48	20.44	99.94	40.86	0.02	0.00	0.02	0.02	0.04	0.04	0.01	0.05	0.00	31.19
	BCM3-0	121.60	171.00	110.40	0.20	19.39	88.05	34.96	0.00	0.00	0.01	0.04	0.04	0.06	0.00	0.04	0.00	28.49
M-3	BCM3-25	101.00	328.40	102.20	0.20	21.27	87.27	33.67	0.01	0.00	0.01	0.06	0.02	0.07	0.00	0.01	0.00	26.41
03 Aug	BCM3-50	90.00	126.00	106.60	0.60	18.72	90.36	36.91	0.01	0.00	0.01	0.02	0.05	0.02	0.03	0.14	0.00	29.74
2009	BCM3-75	87.60	46.40	104.40	0.00	16.40	90.16	45.64	0.04	0.00	0.01	0.03	0.01	0.01	0.00	0.11	0.00	34.93
	BCM3-100	98.20	42.20	101.80	0.60	16.46	98.84	49.18	0.00	0.00	0.02	0.00	0.00	0.02	0.01	0.00	0.00	34.86
	Mean	99.68	142.80	105.08	0.40	18.45	90.94	40.07	0.01	0.00	0.01	0.03	0.02	0.04	0.01	0.06	0.00	30.88
	BCM4-0	110.00	110.60	77.00	0.20	19.48	91.98	36.64	0.01	0.00	0.02	0.00	0.12	0.06	0.02	0.03	0.00	28.43
M-4	BCM4-25	94.00	102.40	77.80	0.00	21.41	112.94	42.46	0.00	0.00	0.01	0.00	0.20	0.01	0.02	0.00	0.00	28.17
26 Sep	BCM4-50	98.40	106.20	81.20	0.00	18.11	94.88	41.42	0.02	0.00	0.03	0.00	0.00	0.02	0.00	0.12	0.00	30.15
2009	BCM4-75	92.00	52.40	81.60	0.00	16.73	100.08	46.88	0.00	0.00	0.01	0.00	0.00	0.03	0.00	0.02	0.00	32.49
	BCM4-100	99.20	49.00	87.00	0.00	15.44	87.04	53.00	0.00	0.00	0.01	0.00	0.01	0.01	0.00	0.11	0.00	35.69
	Mean	98.72	82.92	80.92	0.20	18.23	97.38	44.08	0.01	0.00	0.02	0.00	0.07	0.03	0.01	0.06	0.00	30.99

In the monitoring-2 area, cation content in the water samples is similar to monitoring-1. The average concentration of each major cation (K, Ca, Mg and Na) only differs by about 2 mg/L. However, anions content show significant different with monitoring 1. The highest level of chloride, nitrate and sulphate concentration (178.00 mg/L, 71.00 mg/L and 183.60 mg/L respectively) can be found at the surface level. Chloride, nitrate and sulphate concentration is observed decreasing with depth. The impact of fertilizer after monitoring-1 is quite clearly seen in the extracted water content.

In monitoring-3, the highest nitrate concentration (328.40 mg/L) is observed at depth of 25 cm and reduced gradually with depth. In this survey (monitorin-3), nitrate concentration is higher than in the monitoring-2. Meanwhile the highest value of chloride (121.60 mg/L) is observed at surface and decreases gradually with increasing depth. The same trend is also recognized for sulphate concentration, which the highest (110.40 mg/L) value is near surface. The average chloride and nitrate content are 99.68 mg/L and 142,8 mg/L which are around 0.83 and 3.26 times respectively higher than in monitoring-2. Cations content is relatively similar to the previous two surveys.

Monitoring-4 is the last survey site in this study. Highest nitrate concentration (110.60 mg/L) is obtained at the surface and decrease gradually with depth. However, at the two deepest sampling depths (75 cm and 100 cm), the nitrate concentration are more than in monitoring-2. The highest chloride concentration (110.00 mg/L) could be found near surface and it decreases at 25 cm depth sampling and increase gradually with depth. This trend is also noted for sulphate concentration. In general, the cations content are relatively similar for every time lapse measurement. Figure 6.39 shows the average concentration of anion content in the water samples ranging from 0 cm to 100 cm depth and the near surface (0-25 cm) for each monitoring.

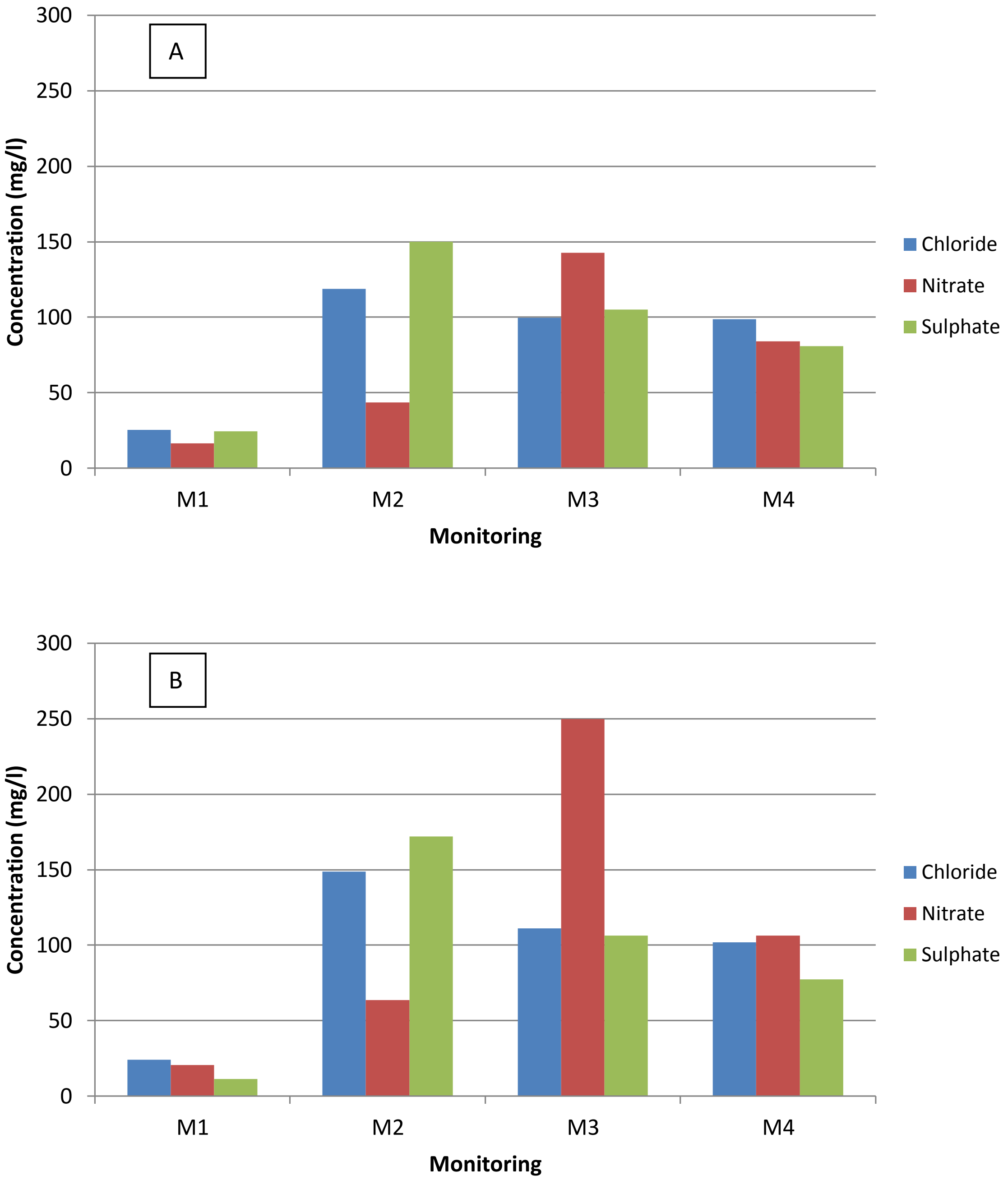


Figure 6.39. (A) Average concentration of anion content ranging from 0 cm to 100 cm depth and (B) from 0 cm to 25 cm depth versus time lapse monitoring.

6.4.3. Geoelectrical Resistivity Model

The geoelectrical resistivity models for all monitoring surveys are given in Figure 6.40.

Monitoring-1

In the geoelectrical model along line BC11, the highest resistivity value (more than 250 ohm.m) occur near surface especially towards the half right side of the section. The value is also supported by ten random point of direct surface resistivity measurement which has an average of 176.80 ohm.m with standard deviation of 62.42 ohm.m. This corresponds to the find sand with low moisture content. In profile of line BC12, the same pattern of resistivity value in line BC11 is also observed near the surface. A resistivity value of around 50 ohm.m is obtained at the depth ranging from 1.10 - 2.50 m, corresponds to the zones with freshwater content. In the deeper depth, ranging from 2.50 - 4.50 m, the resistivity value are relatively higher, correlate to less porous zone filled with freshwater. On the right side at the same depth, relatively higher resistivity value (around 120 ohm.m) is observed correlating to a more compacted material. The material continues in a southeast-northwest direction (perpendicular to the both lines). The continuity of the material is disturbed at below around the 16 to 20 m mark, but it still can be found to the left side of the section which has higher porosity. In the deepest of the section (more than 5.5 m), the lowest resistivity value less than 8 ohm.m is observed corresponding to brackish water.

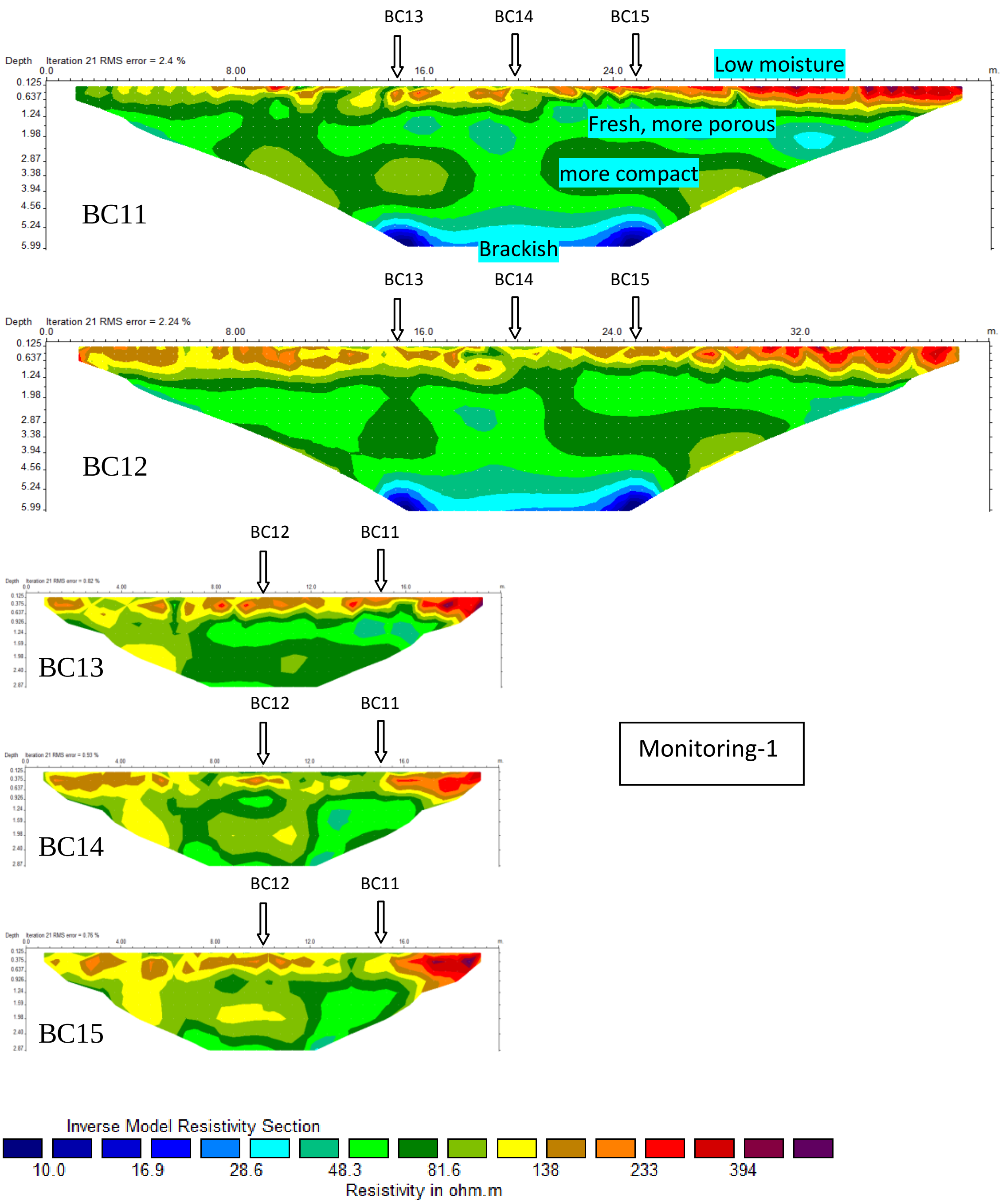


Figure 6.40. Geoelectrical model of Monitoring-1, 2, 3 and 4.

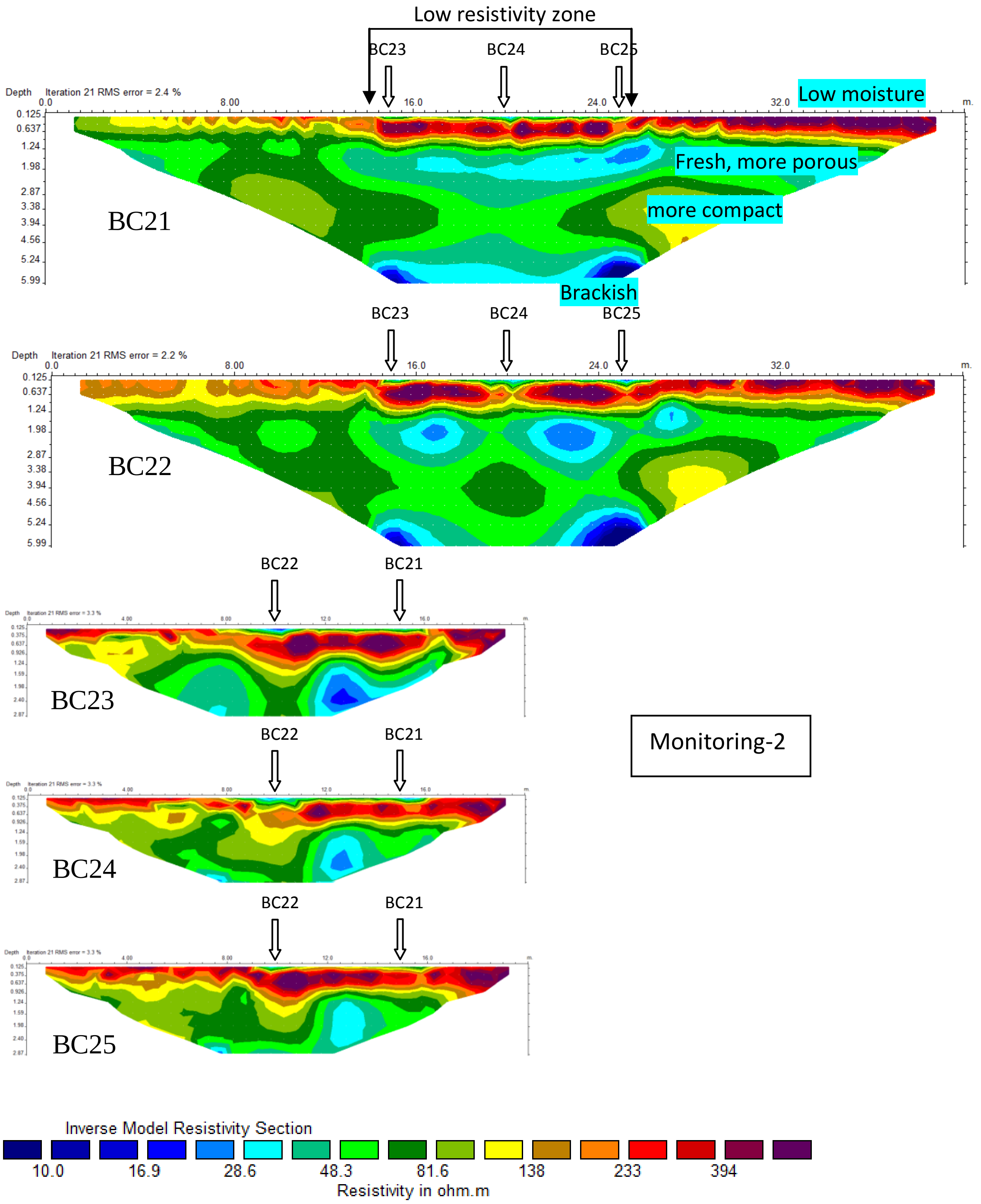


Figure 6.40. Geoelectrical model of Monitoring-1, 2, 3 and 4 (Continued).

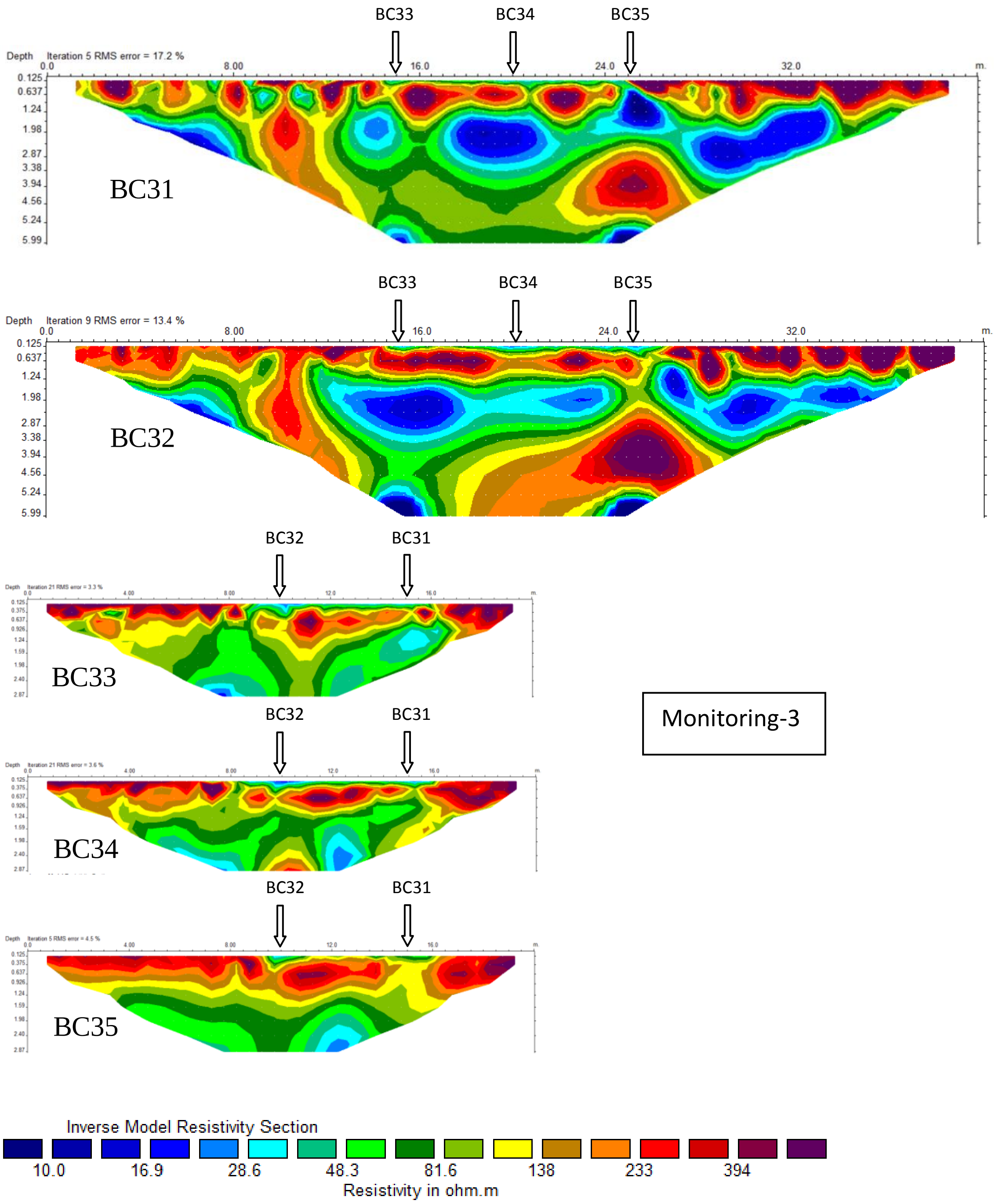


Figure 6.40. Geoelectrical model of Monitoring-1, 2, 3 and 4 (Continued).

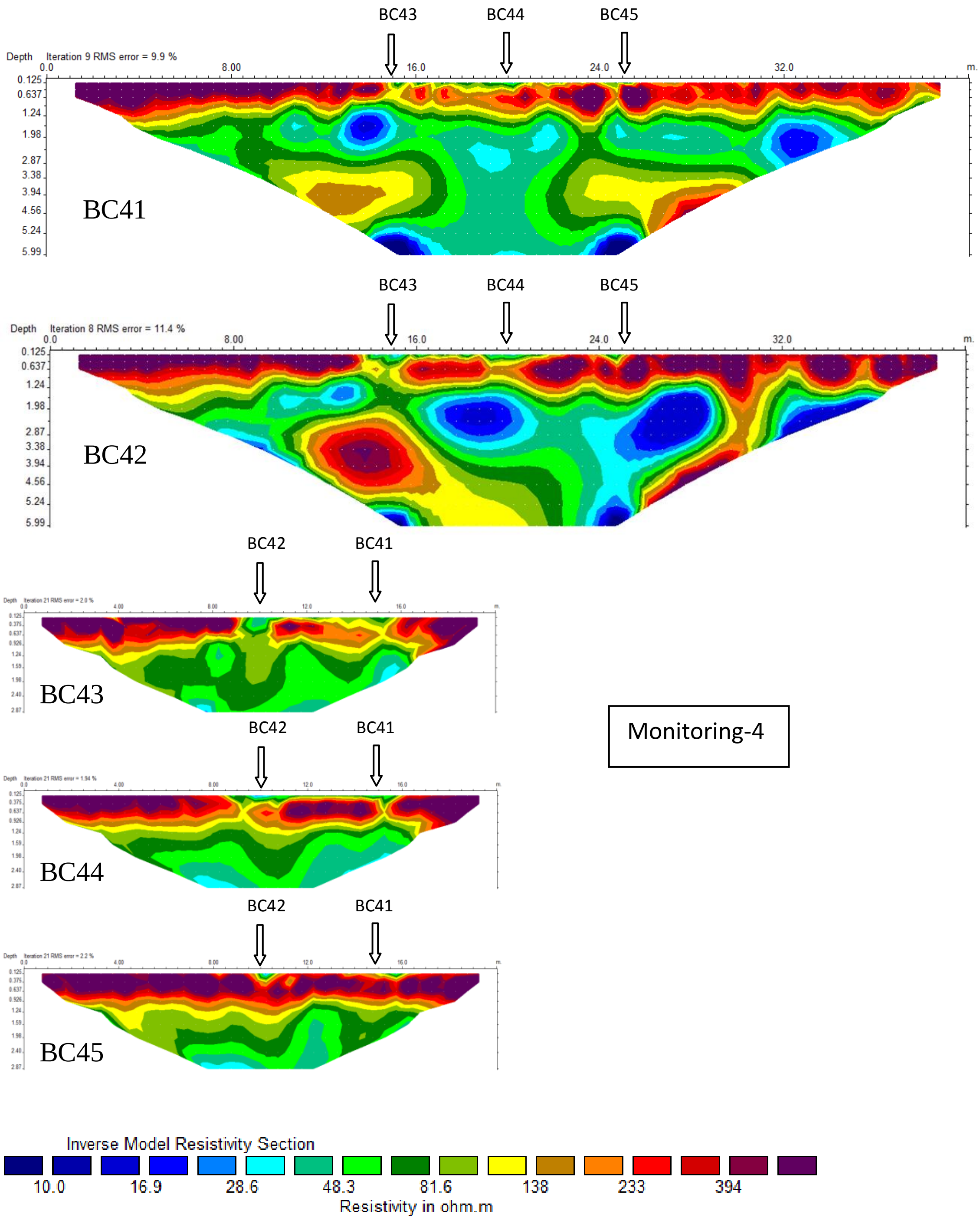


Figure 6.40. Geoelectrical model of Monitoring-1, 2, 3 and 4 (Continued).

In the geoelectrical model along line BC13, BC14 and BC15, relatively higher resistivity value reveal near surface starting from 15.5 m mark until end of the survey line. The relatively same pattern of resistivity value can be observed in the three geoelectrical model. At the zone where the northeast-southwest survey lines cross (the first two lines), a good subsurface correlation can be seen in each other, although the survey lines were made up with different length and different depth penetration. Overall, on the right side of the section for all geoelectrical model (BC13, 14 and 15), the surface resistivity value tend to be higher. This is caused by more compact materials with relatively low moisture content present in the zone as compared to the left side of the section.

Monitoring-2

Along lines BC21 and BC22, the resistivity profile pattern is almost identically similar to monitoring-1 except at the location where chemical fertilizers had been introduced (14.5 to 25.5 m mark). In the fertilization zone, resistivity value decrease drastically. In the geoelectrical model along line BC21, up to 14.5 m mark, average surface resistivity value is 156.01 ohm.m (derived from geoelectrical model extraction). The average surface resistivity value for the fertilized zone is 56.54 ohm.m. Whilst after the 25.5 m mark the average resistivity value is 667.12 ohm.m. These values are supported by direct surface resistivity measurement which in the fertilized zone is 52.02 ohm.m and out of the fertilized area, is 400.71 ohm.m. For the record, the average surface resistivity for BC11 (monitoring-1) at the same zone is 123.98, 169.07 and 332.27 ohm.m. On the four other lines decreasing trends of resistivity value can also be found in the fertilized zone as shown in the line BC21.

Below the fertilized zone in line BC21, the lower resistivity value is observed at a depth of 1.2 m to 2.5 m when compared to the left and the right side of the section which were unfertilized. This trend can be also found on the other lines (BC22, BC23, BC24 and BC25). However, generally, the same trend feature in monitoring-1 can still be observed in monitoring-2 such as, more compact material in the depth of around 4 m deep.

Monitoring-3

In the monitoring-3, average surface resistivity value of 386.03 ohm.m is observed from beginning of the line to the 14.5 m mark (line BC31). Whilst in the fertilized zone average resistivity value is 44.23 ohm.m. After the 25.5 m mark the average resistivity value is 718.72 ohm.m. This value is derived from the geoelectrical model extraction. Again, these values are supported by direct surface resistivity measurements which in the fertilized area is 43.97 ohm.m and out of fertilized area is 634.73 ohm.m. The same trend of resistivity value can also be found in the other four lines. The leaking path of materials from the surface to downward can be clearly seen at the 24.5 m mark zone. The possibility of high concentration of anion moving through this path to deeper level is clearly possible. Compared to BC21 at the same depth location (24;1.5), BC31 shows a decrease in resistivity value that is proportional to an increase in nitrate content. Other lines also show similar trends of decreasing resistivity value due to increase nitrate concentration.

Overall, in the geoelectrical model line BC31 and line BC32, the subsurface resistivity pattern are almost identically similar to monitoring-1 and monitoring-2. Again, except at the location where the chemical fertilizer had been introduced (14.5 to 25.5 m mark), the resistivity value drops down drastically.

Monitoring-4

In the geoelectrical model along line BC41, the similar resistivity pattern near the surface is still observed as shown in the previous monitoring. At location where chemical fertilizers were introduced (14.5 m to 25.5 m mark), lower resistivity value can still be found.

In the line BC41, up to 14.5 m mark, average resistivity value is 305.764 ohm.m, whilst in the fertilized zone is 92.364 ohm.m and after the 25.5 m mark the average resistivity value is again high 856.233 ohm.m. This value is again supported by direct surface resistivity measurement which in the fertilized area is 88.16 ohm.m and out of the fertilized area is 667.75 ohm.m.

Compared to the two previous monitoring, the geoelectrical model for monitoring-4 (BC41) shows a resistivity value of about 14 ohm.m at depth of around 2.3 m. For the previous monitoring, the resistivity value was more than 14 ohm.m within this zone. This probably is due to the leaching of the chemical fertilizer anion content from the surface through the rainfall process. Furthermore, it is also due to anion content from the brackish water goes up trough capillarity process as impact of low input of freshwater from rainfall.

6.4.4. Fate of Nitrate

A graph of the nitrate concentration versus time and nitrate concentration versus sampling depth is given in Figure 6.41 and Figure 6.42, respectively. In Figure 6.41, the maximum nitrate concentration occurs on the surface except at a depth of 25 cm it happen 49 days after introduction chemical fertilizer. While for a depth 50 cm, 75 cm and 100 cm, the maximum value occur at the last survey (after 103 days of fertilizer introduction). In the Figure 6.42, nitrate concentration increase significantly in monitoring-2 for the whole depth sampling. At average, it increases 3.47 times than monitoring-1. However, it decreases with depth almost linearly. Silva, et al., (2005), reported that soil hydrological properties (e.g. water flux) were found more important for explaining different magnitudes of nitrate leaching losses.

The rainfall data (Figure 6.38) from the nearest rainfall monitoring station (Pejabat Pusat Pertanian Bachok, around 3 km from the site) shows that total amount of water inputs in between monitoring-1 and monitoring-2, monitoring-2 and monitoring-3, monitoring-3 and monitoring-4, comprised of 22.4 mm, 123.4 mm, 289.3 mm, respectively. Other water input such as spray irrigation is not a common farming practice in this area. The rainfall occurred between each monitoring making much water in the pore soil significantly especially at the depth more than 50 cm (Figure 6.37). However, at the depth of 0-25 cm, water in pore soil remains relatively lower. This is due to the soil condition is in border line of semi-pervious and pervious soil characters. Based on Figure 6.38, 6.41 and 6.42, again as in palm oil plantation area, there is no significant correlation between amounts of nitrate concentration with rainfall and apparent water content in the pore soil (moisture content).

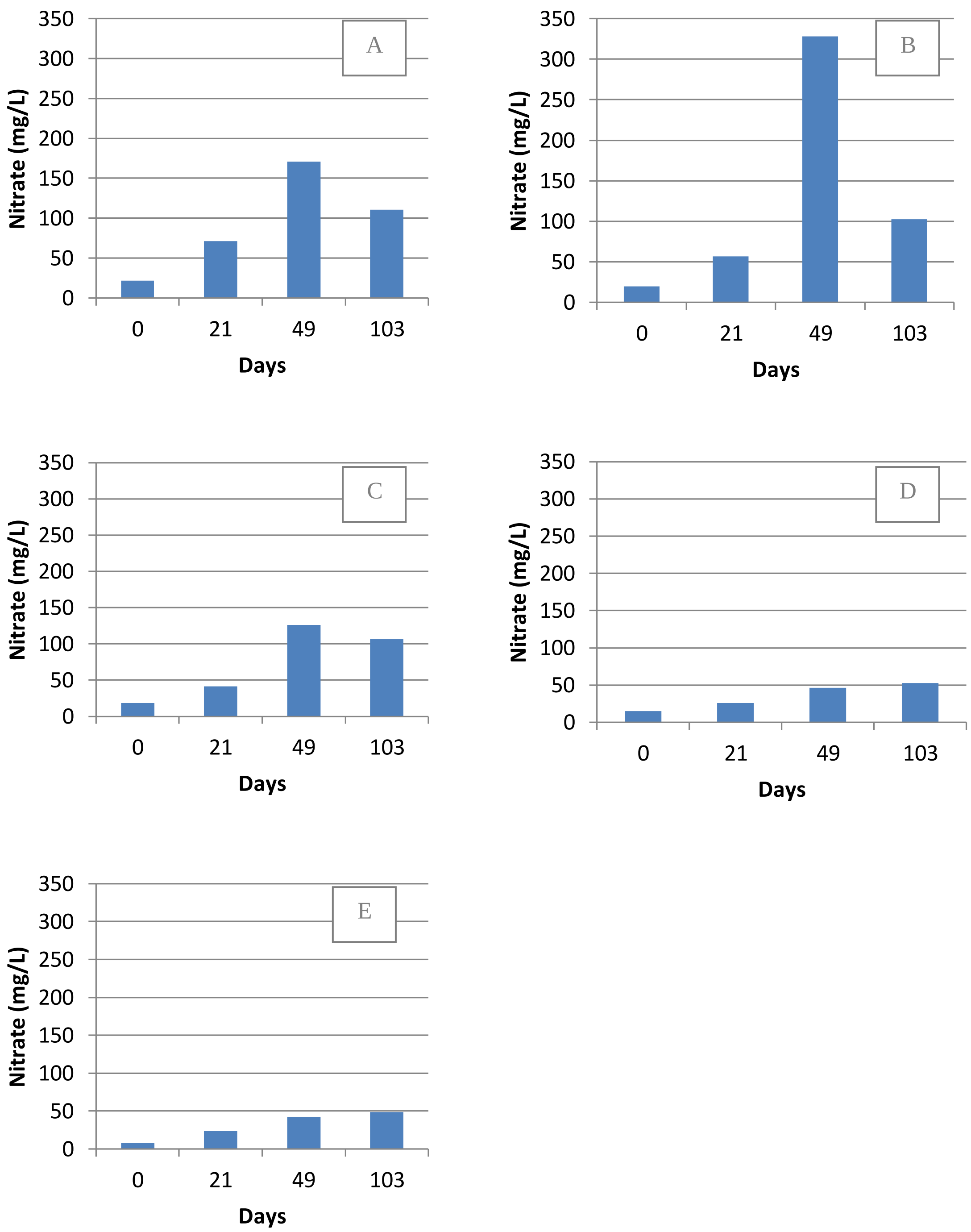


Figure 6.41. Nitrate concentration versus survey time (days) for each depth; (A) surface, (B) 25 cm depth, (C) 50 cm, (D) 75 cm, (E) 100 cm depth

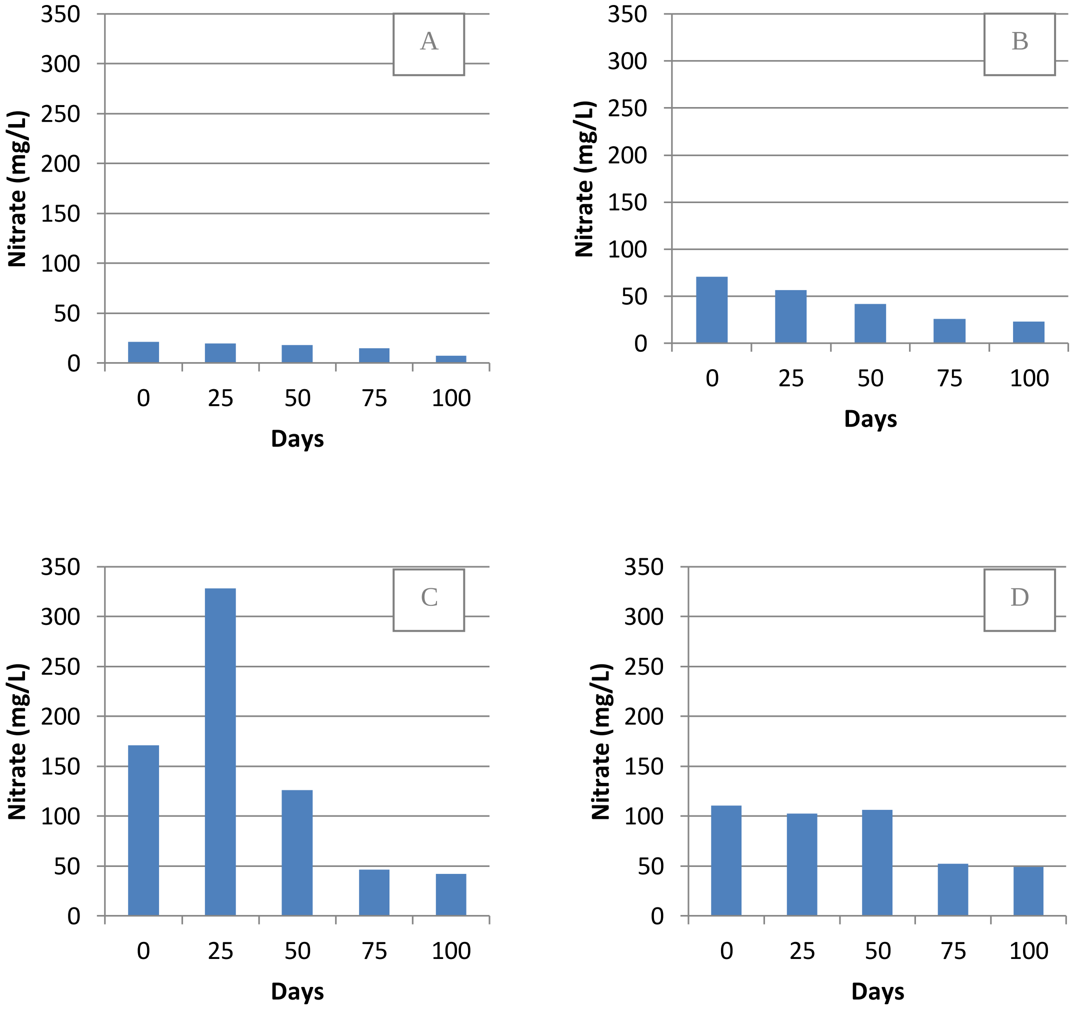


Figure 6.42. Nitrate concentration versus depth for each monitoring (A) Monitoring-1, (B) Monitoring-2, (C) Monitoring-3, (D) Monitoring-3.

Based on Figure 6.41(A), the predicted equation for nitrate concentration (*Nc*) on the surface is developed as the following equation:

$$Nc = (\alpha + \beta.D)/(1 - \gamma.D + \delta.D^2)$$ Equation 6.1

Where α is initial nitrate concentration before fertilizer application (mg/L), β is constant (0.299019), D is days monitoring (no unit), γ is constant (0.0260558) and δ is constant (0.00020295).

In order to see the correlation between Equation 6.1 (predicted nitrate concentration near surface) with measured nitrate concentration data, the Equation 6.1 was plotted together with measured nitrate concentration in the same graph (Figure 6.43). Visually, correlation between predicted and measured nitrate concentration on the surface is very good (0.997).

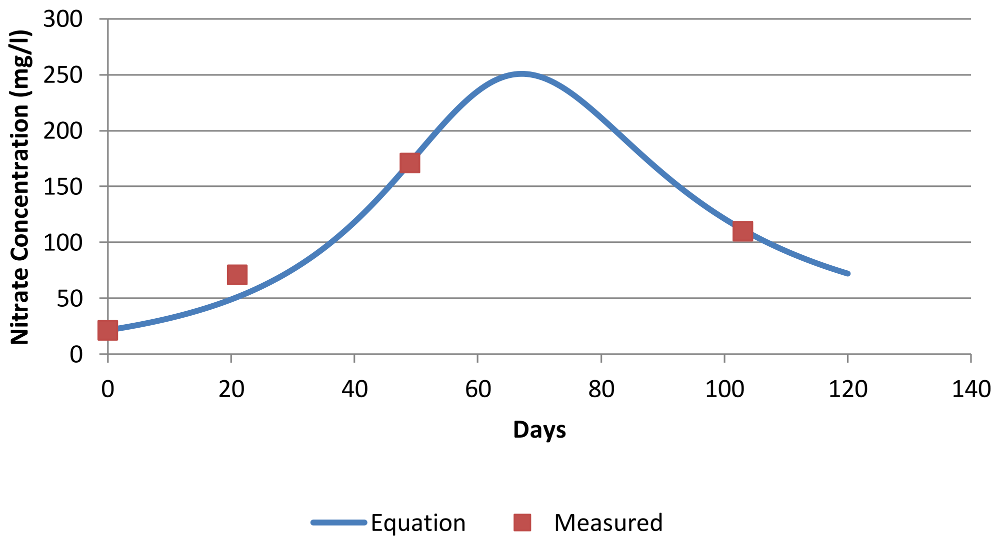


Figure 6.43. Nitrate concentration at the near surface

In this site, nitrate behaviour is slightly different to the nitrate in palm oil plantation area (subchapter 4.4). The maximum nitrate concentration is expected 67 days after fertilization and will be at the initial concentration 195 days after fertilization. Whilst, in Tok Bok the maximum nitrate concentration is 36 days after fertilization and will be at the initial concentration 100 days after fertilization. Although amount of urea introduced in this site is 0.67 times less than in palm oil plantation, however it has long life and the growth of nitrate is 2 times and 1.4 times respectively than in palm oil plantation. This result shows that the soil condition and presence of *Nitrosomonas* bacteria (Lee et al., 2006) is a great factor affecting the fate of nitrate.

6.5. Summary

A laboratory experiment has been done to study the geoelectrical resistivity characteristics in the soil medium filled by a variation of salt water contents. This laboratory study is required in order to calibrate and to improve interpretation of geoelectrical resistivity model. Three areas with different soil characteristics have been studied. Relatively higher resistivity value is obtained from soil sample with 0% of seawater content. For the same seawater mixture content, resistivity value vary with different soil sample. Resistivity value in the soil with smaller grain size distribution (less porous) tends to be higher when compared to the soil with larger grain size distribution (more porous). However, the source of the soil is also affecting the resistivity value. Although marine deposit has small grain size distribution, but residual anion content in the pore soil caused reduce of the resistivity value drastically. When a small amount of seawater presents in the pore water, the resistivity value decrease significantly in all soil samples. Direct resistivity measurement show that soil saturated by brackish water has resistivity value of about 15-17 ohm.m.

A combination of the hydrogeochemical results and interpretation of geoelectrical resistivity indicates that the groundwater in the shallow aquifer is fresh water. This is indicated with low chloride content in the shallow groundwater. In the zone with marine soil deposit, chloride and sulphate concentration tend to be higher in the water sample. However, the concentration is within the accepted limit for human consumption. In places with relatively higher usage of chemical fertilizer, it exhibit higher nitrate concentration in the groundwater. In deeper aquifer, K, Ca, Mg and Na have a positive correlation with chloride concentration, indicating that the ions are derived from the same source of saline waters. The relationship between Cl/HCO3 ratios and chloride also shows mixing of fresh groundwater and seawater, and the samples with lower ratios can be characterized as fresh waters. For the shallow aquifer most ions exhibit a bad correlation to chloride indicating that such ions are derived from a different source. In the zones where the aquifer is filled by salt/brackish water, the geoelectrical resistivity model shows a low resistivity value less than 17 ohm.m. This value will depend on how much percentage of salt water in the aquifer and also soil characteristics of the aquifer. Resistivity value at the depth of around 20-35 m show brackish water present from the beach line until 6-7 km landward. The resistivity value exhibits an increase landward as a decrease of seawater mixture. The line where salt/brackish-fresh water interface occur, shows a curving shape to the river flow around Pengkalan Datu and Kelantan River. This indicates that the water river has a role in increasing subsurface resistivity around it.

Time lapse monitoring of chemical fertilizer have been successful to monitor cation and anion change in tobacco area, Bachok. The hydrogeochemical measurements indicate that the cations content are relatively similar at every time monitoring. However, relatively higher changes of anions content occur near surface. The geoelectrical model prior to fertilization showed similar resistivity value near surface with no significant occurrences of low resistivity value. Lower resistivity value was obtained during monitoring-2, monitoring-3 and monitoring-4 in the fertilized zone. An equation for the growth of nitrate near surface is derived. The maximum nitrate concentration is predicted 67 days after fertilization and will be at the initial concentration around 195 days after fertilization.