Chapter 5

Results and Discussion of Area 2

5.1. Introduction

Area 2 is located in between Area 1 and Area 3. It is bounded by Kelantan River at the western and Gunong Panchor at the eastern (Figure 5.1). It covers an area of 218 km^2 which consist of mainly Kelantan River floodplain zone. Kota Baharu (capital of Kelantan state), is located at the north-western part of the area and cover around thirty percent of Area 2.

The land use are mainly for paddy planting at the flatten land and rubber plantations at the area with relatively higher topography. In some places minor alternating of a rubber trees plantation surrounded by a paddy field can be also found. Intensity of fertilization for paddy planting and rubber tree is lower compared than for palm oil plantation in the Area 1. The farmers in Area 2 plant paddy only once a year, although some plant paddy up to twice a year over several areas. Paddy plants consume a mere 100 kilograms of urea per two hectare a year. For rubber trees, 200 kilograms of urea is utilized for every two hectare per year.

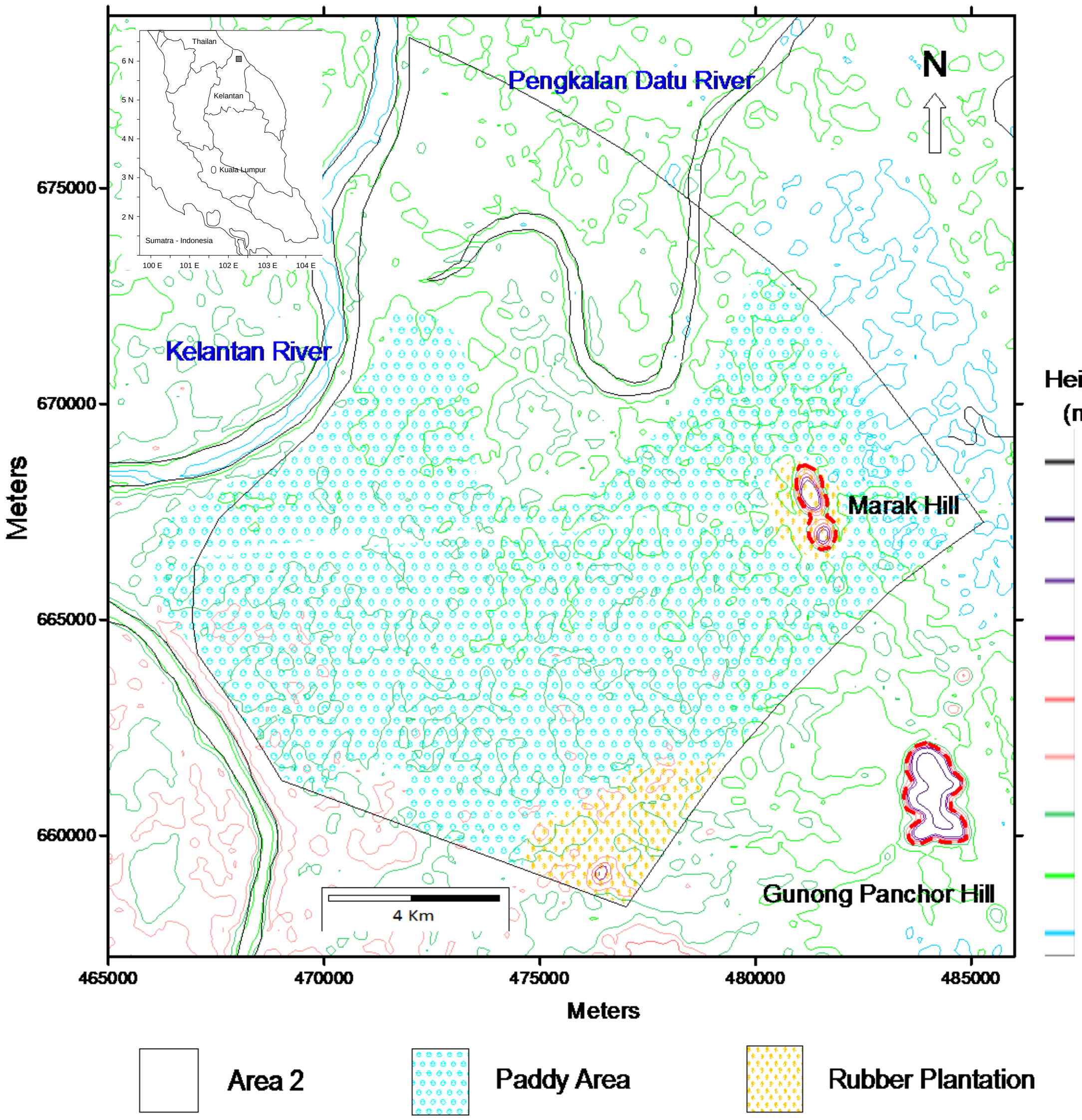


Figure 5.1. Location and land uses map of Area 2.

Urban communities live in this area especially in Kota Bharu use groundwater supplied by the domestic water company (Air Kelantan Sdn Bhd) for their daily activities. In order to supply water, the company extract the groundwater from several pumping well station including Pintu Geng, Perol, Jelawat, and Kubang Kerian, and many others. In some places, the community also use the groundwater from dug well (with depth less than 10 m) to supply domestic water for their daily activities, including for their consumption.

In this chapter, the results and the associated discussion are divided into two main parts.

1. The first part is a discussion on Area 2 groundwater characteristics. In this part, the objective is to search the possibility of groundwater pollution using geoelectrical resistivity and hydrogeochemical methods. It also includes the discussion on hydrogeology and potential aquifer.
2. The second part is focused on heavy metal contamination in groundwater emphasizing on Fe contamination and its distribution along the area. The objective in this part is to trace and delineate the distribution of Fe concentration in groundwater aquifer system.

5.2. Groundwater Investigation for Area 2

Three types of data were collected within this area. They are water sample, geoelectrical resistivity survey and soil sample. The survey location of groundwater sample, geoelectrical resistivity and soil sample is given in Figure 5.2.

Twenty two water sample from existing well (primary data) obtained from this study, together with ten water chemistry result (secondary data) obtained from Jabatan Mineral dan Geosains Malaysia, were used in the interpretation of the overall data. Although the secondary hydrogeochemical data were obtained in 2007 and 2008, they seemed to show results similar to those of the present study and were used for interpretation purposes. The geoelectrical resistivity survey consisted of twenty eight traverse lines. Almost all the survey lines were conducted with maximum spread length of (400 m). The soil grain size distribution analyses were obtained from nine point sample locations especially from the surface level to a depth of 1 m. One well was drilled in order to obtain subsurface data. The grain size distribution data were used to support geoelectrical resistivity interpretation.

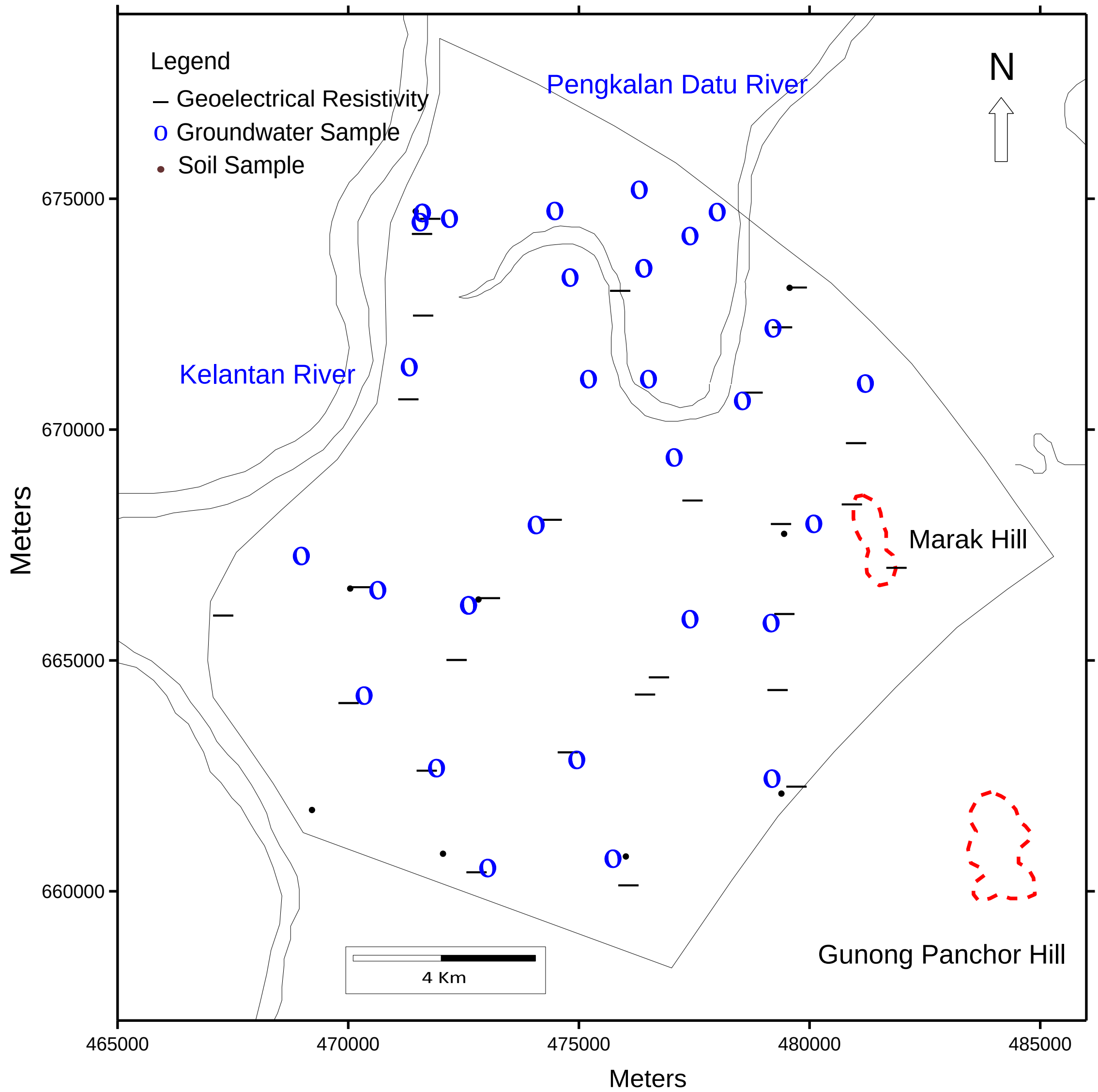


Figure 5.2 Map of survey location for geoelectrical resistivity, groundwater and soil sample within Area 2.

5.2.1. Hydrogeochemical Result

The location of groundwater sampling is given in Figure 5.3. The physical and hydrogeochemical results are given in Table 5.1. The primary data which collected directly in the research are presented in black colour and the secondary data which were obtained from Jabatan Mineral dan Geosains Malaysia are presented in blue colour. The groundwater samples derived from pumping well station (starting with KB) have depth ranging from 11 m (shallow aquifer) to 113.2 m (deepest aquifer). Whilst, the groundwater samples collected from the community dug wells or piezometers (starting with WA2) have depth of less than 10 m (shallow aquifer).

In shallow aquifer (starting with WA2), the hydrogen ion concentration (pH) is slightly acidic (5.58) to slightly alkaline (7.98). Whilst in deeper aquifer (starting with KB), pH ranges from neutral (6.8) to slightly alkaline (8.2). The pH concentration is slightly acidic in the southern part due to it close to the granite bedrock (Boundary Range in the southern part) and it increase to the northern part (due to far from Boundary range).

Magnesium ion (Mg^{2+}) concentration is generally low (< 2.98 mg/L) in shallow aquifer except for well WA209 (18.52 mg/L). The relatively higher magnesium ion in WA209 could be explained by occurrence of magnesium in the fertilizer for corn planting at this site. Whilst in deeper aquifer, magnesium concentration ranges from 1.3 to 4.5 mg/L. There is no specific trend of magnesium distribution observed in term of location and depth sampling.

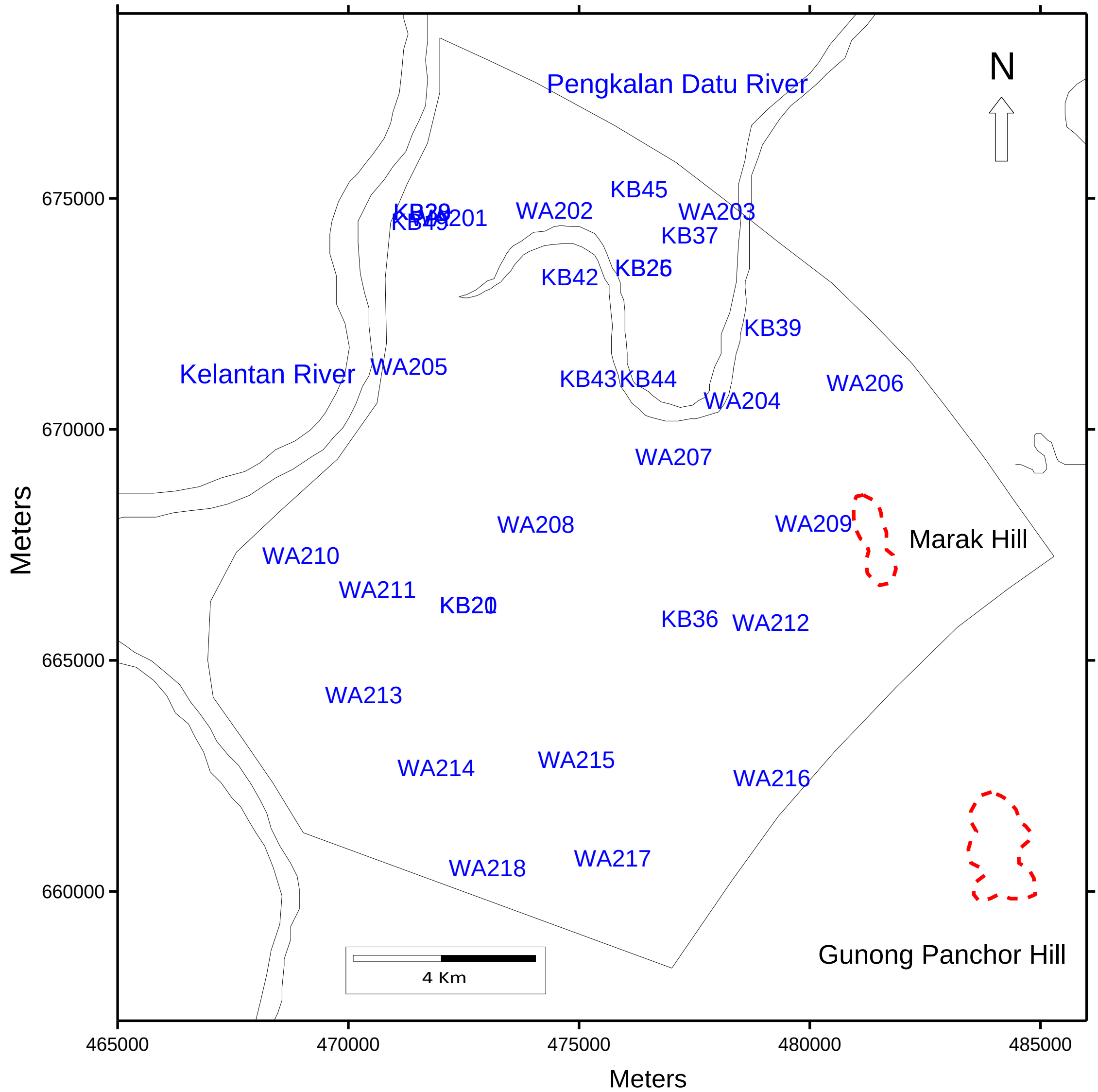


Figure 5.3. Wells location of groundwater sampling. The shallow well name is started with WA2.

Low concentration of sodium (Na) and potassium (K) are obtained in the shallow water samples. The concentration ranging from 1.21 mg/L to 5.11 mg/L and 0.79 mg/L to 5.11 mg/L for Na and K, respectively. Relatively higher sodium (13.64 mg/L) and potassium (22.99 mg/L) concentration are observed in the well WA209 due to the fertilizer activity. Another factor for relatively higher Na and K concentrations in this well are probably due to the location of well WA209 near to the exposed granite (Marak Hill, Figure 5.3). Weathering of K-Feldspars and leaching of clay minerals is probably occurring in this area (Azman, 2005). In the deeper aquifer, sodium concentration ranges from 5.7 mg/L to 62 mg/L and potassium ranges from 1.2 mg/L to 5.34 mg/L. The concentration of aluminium ion (Al^{3+}) is less than 1 mg/L except in WA216 which has 1.46 mg/L. Generally, Na and K concentration in water is safe for human consumption (WHO, 1984).

Relatively higher Fe concentration (>10 mg/L) is observed in the deeper aquifer. Whilst in the shallow aquifer, Fe concentration ranges from 0 mg/L to 5.33 mg/L. All water sample derived from deeper aquifer is not safe for human composition (> 0.3 mg/L). Sixty percent groundwater sample from shallow aquifer is safe for human consumption (< 0.3 mg/L). Fe concentration in Area 2 is significantly different from that of in Area 1. In Area 1, Fe concentration is not exceeding of 0.3 mg/L except in well WA117 (1.99 mg/L). Detailed discussion on Fe contamination in aquifer system is presented in Subchapter 5.3.

Chloride concentrations in shallow aquifer and deeper aquifer are generally low which range from 1.08 mg/L to 7.87 mg/L and 2 mg/L to 20 mg/L, respectively. These values show that there is no salt/brackish indication in the groundwater. The concentration of rain water by evapotranspiration may be an important source of chloride in the area. Other important factors as chloride source are chemical fertilizer used for paddy and corn planting in farming activities. The chloride concentration in water samples are within the accepted limits for human consumption (WHO, 1984).

Table 5.1. Water chemical result of groundwater sample in Area 2. In the bottom row of the table, limit concentration for domestic use by WHO (1992) and U.S.EPA (2002) is displayed

No	Sample ID	X	Y	Well Depth m	Ground Level m	Depth to Water m	Water Level (msl)	TDS mg/L	Cond µS/cm	Sal 0/00	T C	pH
1	KB20	472600	666200	44.8	8.84	2.98	5.86	46.8	98.1	0	31	6.03
2	KB21	472600	666200	29	8.81	4.03	4.78	52	107.7	0	30.7	6.04
3	KB25	476400	673500	52.9	6.44	5.45	0.99	86	94	None	None	7.1
4	KB26	476400	673500	33.5	6.44	5.14	1.3	74	103	None	None	7
5	KB28	471600	674700	113.2	6.07	7.95	-1.88	104	107	0	28.7	7.1
6	KB29	471600	674700	62.2	6.08	7.99	-1.91	44.7	95.1	0	30.2	6.17
7	KB30	471600	674700	14.2	6.01	7.43	-1.42	44.7	96.5	0	28.6	5.24
8	KB36	477400	665900	35.5	5.87	3.23	2.64	56	76	None	None	7.2
9	KB37	477400	674200	13	4.11	3.49	0.62	174	102	None	None	6.8
10	KB39	479200	672200	16.5	5.88	1.95	3.93	78	131	None	None	8.1
11	KB42	474800	673300	11	6.18	5.13	1.05	48	67	None	None	8.2
12	KB43	475200	671100	15	6.26	5.12	1.14	44	57	None	None	7.1
13	KB44	476500	671100	14.8	5.67	4.52	1.15	86	123	None	None	7.9
14	KB45	476300	675200	12	6	4.76	1.24	84	137	None	None	7
15	KB49	471550	674500	14	7.44	3.8	3.64	104	182	None	None	7.4
16	WA201	472187	674575	6	7	3.1	3.9	119.5	217.12	0	27	6.73
17	WA202	474470	674742	<7	7	2.4	4.6	22.7	45.24	0	26.7	7.81
18	WA203	477990	674718	<7	7	None	None	12.4	26.3	0	26.3	7.6
19	WA204	478537	670628	<7	7	None	None	28.4	48.71	0	25.7	6.89
20	WA205	471314	671360	6	12	3.1	8.9	20.1	46.74	0	30	6.7
21	WA206	481202	671004	<7	12	2.65	9.35	10.8	25.11	0	29.5	7.98
22	WA207	477057	669403	<7	8	1.9	6.1	11.7	27.2	0	29.1	7.34
23	WA208	474066	667941	<7	13	2.8	10.2	26.9	45.53	0	28.7	6
24	WA209	480084	667965	6	11	2.3	8.7	144.7	301	0.1	31.2	6.04
25	WA210	468975	667269	6	12	2.26	9.74	13.9	32.3	0	29.3	6.65
26	WA211	470633	666528	<7	12	2.23	9.77	21.6	50.2	0	28.5	6.24
27	WA212	479159	665816	<7	11	2.09	8.91	22.5	52.3	0	29.2	6.31
28	WA213	470336	664245	<7	12	2.22	9.78	18.9	43.9	0	28.6	6.37
29	WA214	471906	662674	<7	12	1.8	10.2	12.3	28.6	0	28.1	6.51
30	WA215	474946	662852	8	13	2.6	10.4	27.5	41.05	0	30.3	5.58
31	WA216	479179	662447	6	15	2.8	12.2	15.3	32.2	0	32.2	5.85
32	WA217	475731	660712	<8	22	3.4	18.6	19.3	40.8	0	27.2	5.77
33	WA218	473016	660510	5	11	1.81	9.19	15.2	35.3	0	28.1	6.16
												6-8

Table 5.1. (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	KB20	2.63	0.12	0.379	0.265	4.697	5.335	3.301	9.502		12.07	0	6.7
2	KB21	2.55	0.11	0.329	0.343	4.889	6.769	4.517	7.459	0.134	13.17	0	0
3	KB25	3	3.9	<5	<0.5	5	4.3	2.1	8.6	0	10	<1	48
4	KB26	2	4.7	<5	<0.5	3.8	5.2	3.1	7.6	0	7.6	<1	54
5	KB28	2.9	0.1	0.238	0.339	8	3.5	3.7	8.5	0	10	<1	54
6	KB29	3.19	0.17	0.317	0.168	5.363	2.879	3.302	7.867		12.99	0	3.4
7	KB30	10.12	5.84	6.215	0.015	2.128	2.992	1.524	10.13		0.43	0	0
8	KB36	4	2.4	9	<0.5	6.6	2.6	2.4	5.7	0	9.4	<1	29
9	KB37	6	<0.5	15	<0.5	2.7	6	2.9	62	0	3	<1	205
10	KB39	20	1.5	10	<0.5	1.7	0.9	1.6	21	0	0.7	<1	17
11	KB42	6	4.3	<5	<0.5	1.6	3.5	1.8	5.9	0	0.1	<1	23
12	KB43	6	5	<5	<0.5	1.2	2.6	1.3	4.6	0	11	<1	16
13	KB44	12	4.3	14	<0.5	1.8	2.6	1.6	20	0	1.4	<1	31
14	KB45	8	9.7	6	<0.5	2.8	8.2	1.3	7.9	0	2.3	<1	33
15	KB49	12	1.4	14	5	3.1	23	2.6	9.2	0	2.3	<1	70
16	WA201	6.3	16.5	11.25	0.155	3.068	6.475	2.978	8.462	0.135	0.796	0	6.2
17	WA202	1.08	0	0.545	0	2.364	4.018	2.384	6.284	0.245	0.642	0	22.4
18	WA203	3.31	2.05	9.642	0.122	1.456	2.845	1.384	5.845	0.125	0.587	0	15.4
19	WA204	3.42	0	2.203	0.069	3.143	4.797	1.047	4.382	0.132	0.263	0	14
20	WA205	5.63	0	0.881	0	1.029	3.746	0.455	2.098	0.215	0.072	0	0
21	WA206	1.65	0	0	0	0.824	3.71	0.426	0.86	0.064	0.107	0	0
22	WA207	1.59	0	0.169	0	1.024	4.779	0.571	1.589	0.032	0.044	0	1.8
23	WA208	2.9	0	2.684	0.08	2.431	2.604	0.753	2.895	0.176	0.332	0	7.6
24	WA209	7.87	0	192	0.329	22.99	59	18.52	13.64	0.122	0.491	0	113.4
25	WA210	1.63	0	0	0	1.038	5.433	0.598	1.423	0.056	0.062	0	9.3
26	WA211	1.83	0	0	0	1.057	5.88	0.671	1.746	0.035	0.061	0	115
27	WA212	6.19	0	0.881	0	0.795	4.174	0.466	1.983	0.29	0.122	0	0
28	WA213	5.95	0.53	0	0	0.961	4.537	0.548	2.13	0.1	0.103	0	2.6
29	WA214	2.27	0	0	0	0.992	4.782	0.517	1.214	0.02	0	0	9.1
30	WA215	3.61	0	0.788	0	1.805	2.529	0.576	2.915	0.126	1.016	0	11.2
31	WA216	5.12	0	0.483	0.05	5.111	7.064	1.28	5.113	1.464	5.333	0	48.2
32	WA217	4.29	0	0.696	0	3.983	2.114	0.711	2.566	0.282	0.671	0	16.2
33	WA218	2.14	0	0.475	0	1.26	3.971	0.498	1.346	0.047	0.013	0	12.3
		250	45	400	1.5			150	200	0.2	0.3		

Nitrate concentrations in the sampled area are ranging from 0 mg/L to 9.7 mg/L except in well WA201 that has nitrate concentration of 16.5 mg/L which is the highest in this area. The potential source of nitrate in this site (WA201) may be caused by animal excrement that infiltrate trough the soil. The animal farming (duck farming) was found around 20 m from the well. Generally, the concentration of nitrate in the sampled area is generally within the accepted limit for human consumption.

The sulphate concentration ranges from 0.00 – 11.25 mg/L except in well WA209 where sulphate concentration is 191.98 mg/L. The major source of sulphate in this site (around WA209) is believed from chemical fertilizer activities. However, the concentration value is still below the accepted limits for human consumption.

5.2.2. Geoelectrical Resistivity Result

The central point of the geoelectrical surveys are plotted at a map as given in Figure 5.4. Interpretation for geoelectrical resistivity model will be based on result presented in Subchapter 4.2. The analysis and discussions for the entire geoelectrical models stated from near surface and subsequently to the deepest depth. The following terminations are used as label in all of the interpreted geoelectrical models: CSL = Compacted soil with low moisture content; SA = Shallow aquifer; PA = Potential aquifer; GB = Granite basement; GBl = Granite boulder.

Pintu Geng

Pintu Geng is a name of pumping well station (12 m above mean sea level) located around 1.7 km from the nearest bank of the Kelantan River and 11.3 km from the nearest beach line. At the Pintu Geng pumping well station, there are four production wells that produce 1 million litres water per hour every day (Ismail, 1992). Beside production wells, the other three wells KB28, Kb29 and KB30 with different depths are used for monitoring physical and chemical properties of the groundwater in each aquifer.

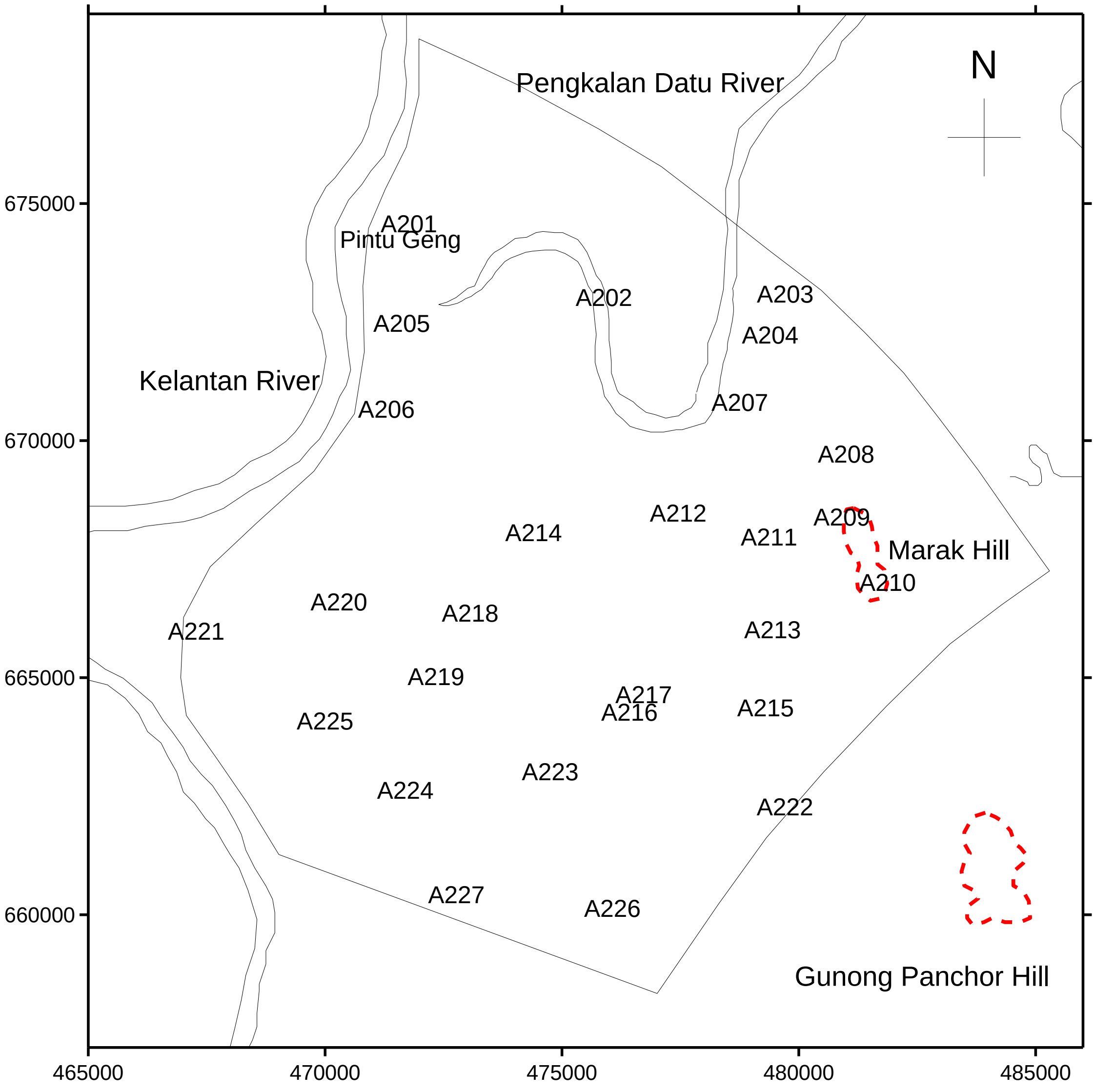


Figure 5.4. Location of geoelectrical resistivity survey in Area 2.

At this site, there was no longer enough space to lay a long cable for the geoelectrical resistivity survey. A dry grass field of 150 m length was used to perform geoelectrical resistivity survey using two wheels cable with 41 electrodes. Each electrodes were spaced 2.5 m from each other. The survey was conducted between two production wells.

Figure 5.5.A shows the subsurface lithology from the surface to a depth of 32 m (-20 m) obtained from gamma ray log interpretation. Relatively higher gamma ray value is observed from the surface to a depth of 2 m corresponding to clay. At a depth from 2 to 10 m, sand formation is found which is indicated by relatively low gamma ray value. Alternating high and low gamma ray value is observed at a depth from 11 - 30 m. This indicates alternating of clay and sandy clayey. Water level in the shallowest well KB30 (10.5 m deep) was measured at 8.83 m depth. The well was 123.6 m from the survey line and perpendicular to the geoelectrical model at 25 m mark (Figure 5.5.B). However, in the zone below the survey line, the water table was believed to be deeper than the 8.83 m depth. It was due to the two shallow production wells located at the end and at the beginning of the line.

In this area, there was no rainfall within 3 weeks before the survey was done. It caused the soil in this site very dry and mostly made of the died grass. Figure 5.5.C shows a view in the Pintu Geng pumping well station.

The geoelectrical model of Pintu Geng survey is given in Figure 5.5.B. A dominant resistivity value of about 300 ohm.m is observed from near surface to a depth of around 11 m. It is also supported by the direct resistivity measurements taken from five points with an average of 481.50 ohm.m and a standard deviation of 29.43 ohm.m. The values correspond to the clay material with very low moisture content.

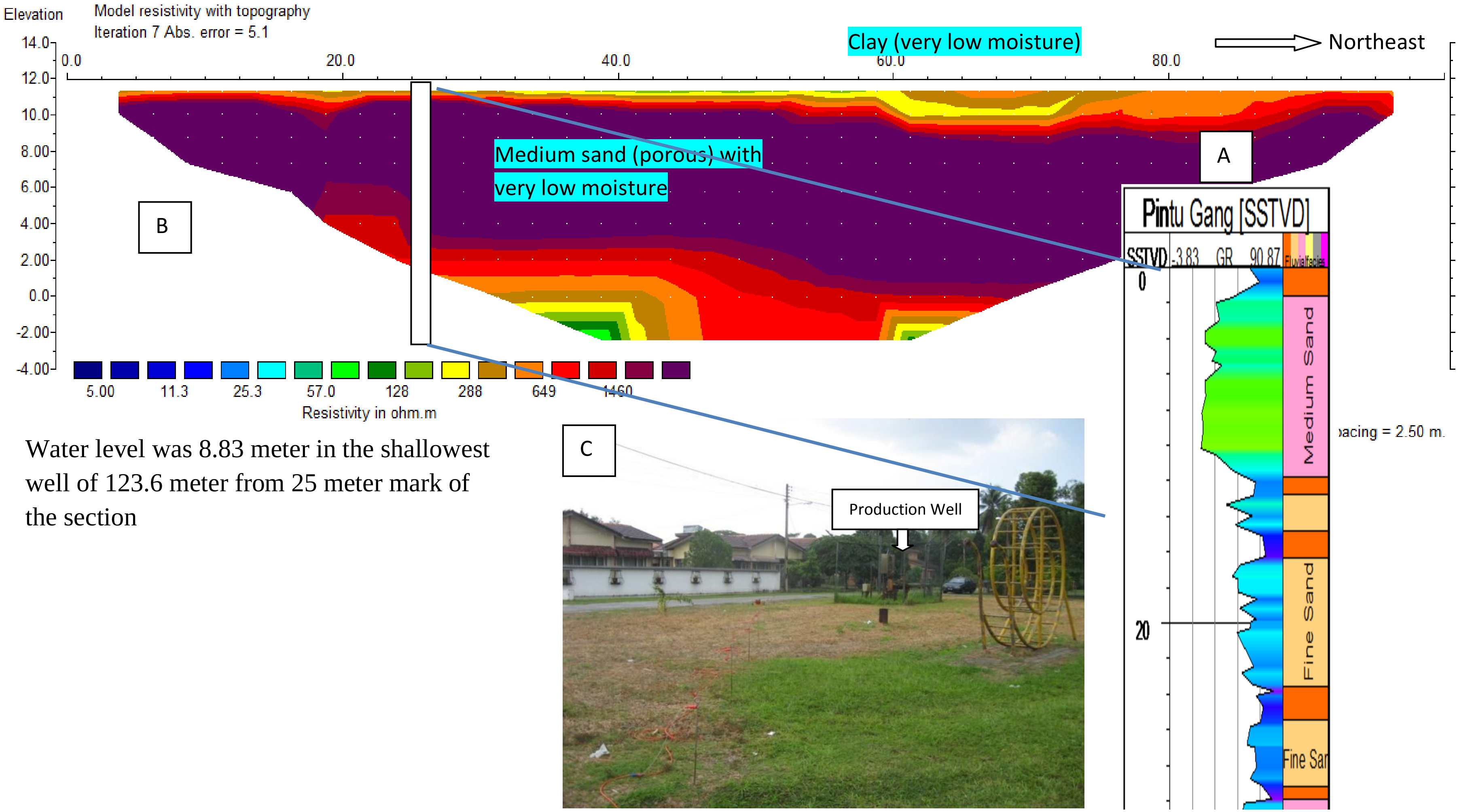


Figure 5.5. (A) Geoelectrical model of Pintu Gang line, (B) Gamma ray interpretation, (C) View at the survey line.

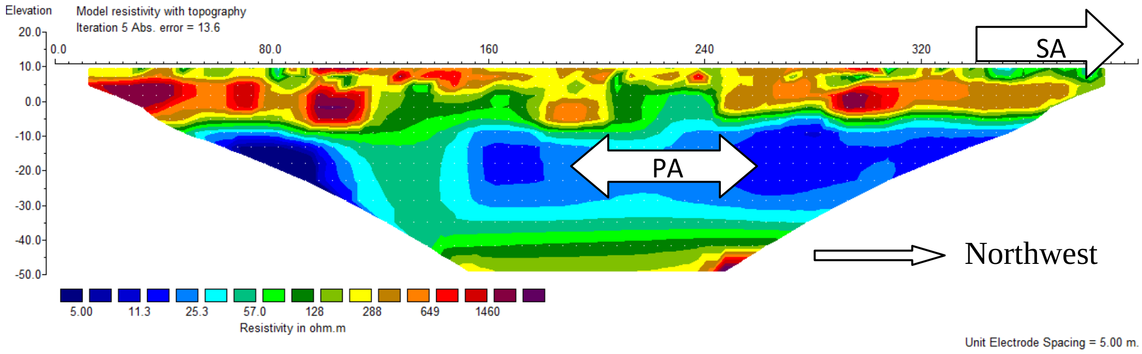
Below the clay layer, other formation is observed with higher resistivity values of more than 2000 ohm.m. It corresponds to the sand formation with very low moisture content. Obviously the main cause of low moisture content is due to no rainfall within three weeks and high pumping rate in this site (especially at the beginning and ending of the line). Resistivity value of about 300 ohm.m is obtained at the deepest depth, corresponding to the saturated sandy clayey layers. This is also supported by gamma ray interpretation and in-situ physical well measurement that indicated the clayey sand layers are filled with fresh water at this depth (water level = 8.83 m, chloride = 10.118 mg/L). Overall, the geoelectrical model, direct resistivity measurement, gamma ray interpretation and the in-situ physical well measurement are showing good correspondence and supporting each other.

Line A201

Line A201 was conducted at a site 11 m above mean sea level and located adjacent to the drainage system. The water in the drainage system was about 5 m below the ground surface. The site was located 450 m from Pintu Geng pumping well station. The survey line direction was almost from the north to the south.

A high-resistivity anomaly (about 250ohm.m) is observed near the surface along line A201 (Figure 5.6), corresponding to the clayey sand soil with low moisture content. However, a puddle of water was found near 30 m and 360 m mark. After 360 m mark, relatively lower resistivity value (about 60 ohm.m) from near the surface until 5 m depth is obtained and interpreted as shallow aquifer. Further down, lower resistivity value (< 10 ohm.m) is observed at the depth of -9 to -24 m. This value is similar to the resistivity of light brackish water in the aquifer (Chapter 6). The water chemical analysis result of KB29 and KB30 (nearest well from this line) shows there is no indication of brackish water. Detailed discussion regarding this matter (low resistivity anomaly) will be discussed in the next subchapter (5.3).

A resistivity value of around 10-60 ohm.m is observed at depth of about -15 to -24 m, corresponding to the potential aquifer. This interpretation is also supported by gamma ray interpretation indicates the presence of sand formation about at similar depth from -15 to -24 m. A thicker clay formation is found underlying the sand at depth of 38 m to 50 m. The basement bedrock occurs at a depth of 112 m based on drilling information of Pintu Geng wells. There is no basement bedrock indication shown in the geoelectrical model.



SA = shallow aquifer; PA = Potential aquifer

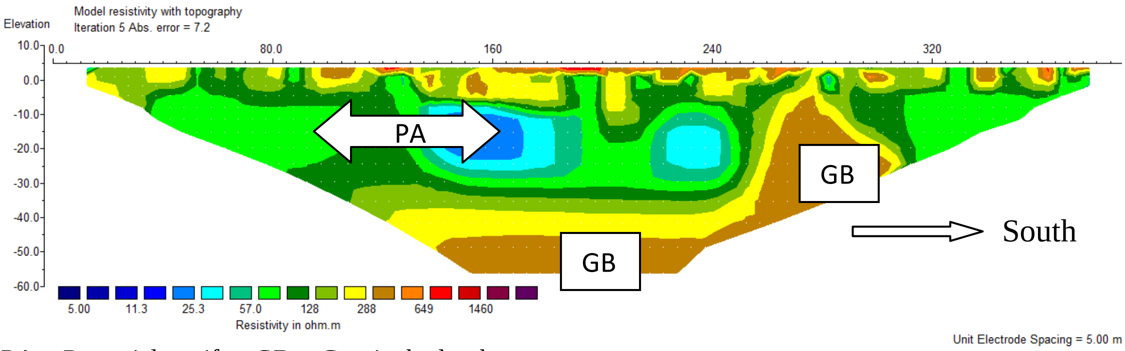
Figure 5.6. Geoelectrical model of line A201.

Line A202

Line A202 was located at a site with elevation of 5 m above mean sea level. The survey line was conducted on the sand bar of Pengkalan Datu River in a north-south direction. The water in the Pengkalan Datu River was about 1 m below the ground surface.

In the geoelectrical model of line A202 (Figure 5.7), a relatively higher resistivity value is observed near the surface, corresponding to the compacted clay with low moisture content. The relatively lower resistivity values (25-60 ohm.m) can be found at a depth of -5 m to -25 m. This corresponds to the porous formation of potential aquifer. KB26 and KB42 are the nearest wells to the survey line with maximum depths of 33 m and 11 m respectively (Table 5.1). Chemical analysis of the well water indicate freshwater characteristics.

Visually in the section, relatively higher resistivity value (more than 400 ohm.m) indicates more compacted material below 250 - 290 m mark from a depth of -7 m down. It probably corresponds to the granite basement. This interpretation is also supported by drilling information that informed where granite bedrock is found at depth of 57 m in wells KB25 and KB26. These wells are located at 650 m to northeast of the line survey.



PA = Potential aquifer; GB = Granite bedrock

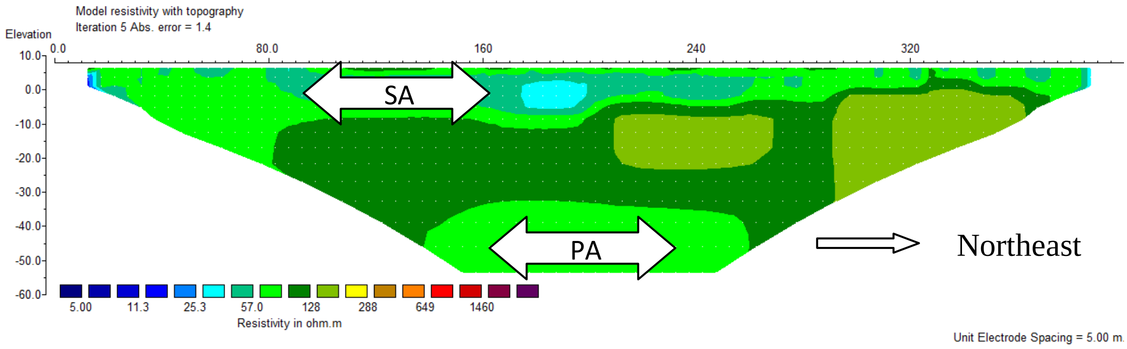
Figure 5.7. Geoelectrical model of line A202.

Line A203

Line A203 was located at a site with an elevation of 8 m above mean sea level. The line direction was almost from southwest to northeast. The site was surrounded by a paddy field which puddle water was 10 cm below the ground surface.

Along the geolectrical model (Figure 5.8), a resistivity value of about 60 ohm.m dominates near surface from the beginning line to 80 m mark. At the zone after 90 m mark, resistivity value increases to about 100 ohm.m. The value corresponds to the clayey sand material with high moisture content. It was also supported by soil sample taken from this area (A2S11). The soil was composed of fine to medium sand and clay at depth of up to 1 m.

Relatively lower resistivity value (about 30 ohm.m) is obtained at depth of 5 to -2 m. This is interpreted as the shallow aquifer. It is thicker to the southwest and emerges at 75-90 m mark. Relatively lower resistivity value is also obtained from a depth of -32 m down. This corresponds to potential aquifer. However, no basement indication is observed in the geoelectrical model.



PA = Potential aquifer; SA = Shallow aquifer

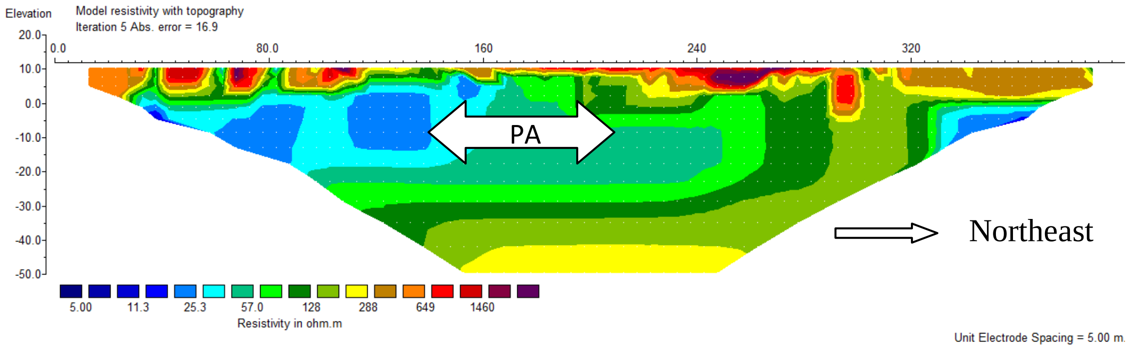
Figure 5.8. Geoelectrical model of line A203.

Line A204

The survey line A204 was performed on a site with an elevation of 12 m above mean sea level. It was conducted in between a minor road and an artificial drainage system. A puddle of water in the drainage system was measured 3.5 m below the ground surface.

In the geoelectrical model along line A204 (Figure 5.9), relatively higher resistivity value of about 500 ohm.m is obtained near the surface. The average direct resistivity measurement is 542.23 ohm.m with a standard deviation of 87.34 ohm.m. The highest resistivity value is observed below 245-260 m mark which corresponds to the minor bridge concrete.

A resistivity value of approximately 30 ohm.m occurs at depth ranging from 2 m to -18 m, corresponding to possibly a potential aquifer. The well KB39 is about 30 m to the south from the survey site indicating that the fresh water content presents at the interval depth. Highly compacted material with less porosity occurs at depth of -38 m down. However, basement is not found in the section.



PA = Potential aquifer

Figure 5.9. Geoelectrical model of line A204.

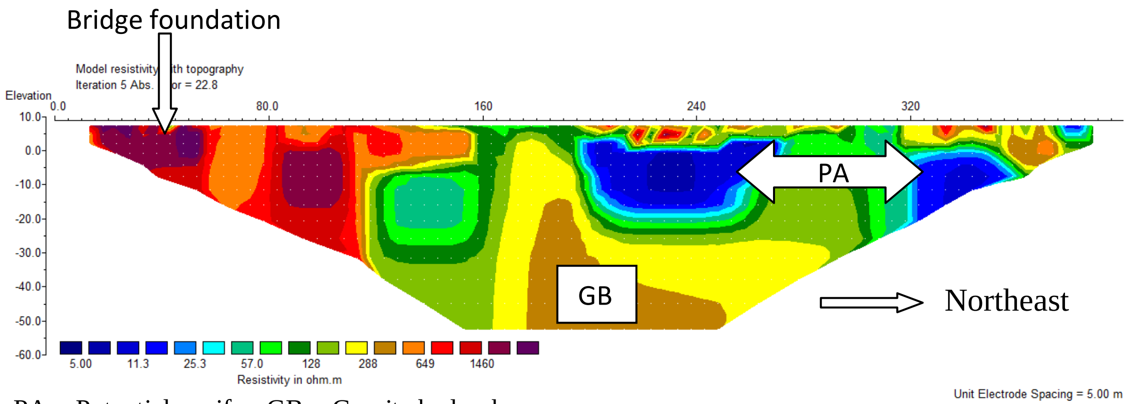
Line A205

The next survey was performed at a site surrounded by a paddy field with elevation of 9 m above mean sea level. The survey line was laid in a southwest-northeast direction. The site survey was 1.9 km to the south of Pintu Geng pumping well station.

The line A205 geoelectrical model is generated from slightly bad inversion process (Figure 5.10). This is indicated by 22.8% of its error after five time iterations. The error was increased if the number of iteration was added. However, this is the best model generated from this survey.

In the geoelectrical model, a relatively higher resistivity value (650 ohm.m) is observed near surface from the beginning of the line until the 130 m mark. It corresponds to the road embankment material and bridge concrete. A relatively lower resistivity value of about 12 ohm.m (dark blue) is observed at depth approximately from 0 to -16 m. This indicates it was as though the presence of brackish water in the aquifer. However, occurrence of brackish water in this site is almost impossible. In addition, the nearest wells from the site towards the seaward (KB28, KB29 and KB30) show no trace of brackish water in the groundwater.

Relatively higher resistivity value (400 ohm.m) occurs at depth of -13 m downwards below the middle of the line. This is probably due to the occurrence of pre-Quaternary bedrock at almost vertically below 170 m mark.



PA = Potential aquifer; GB = Granite bedrock

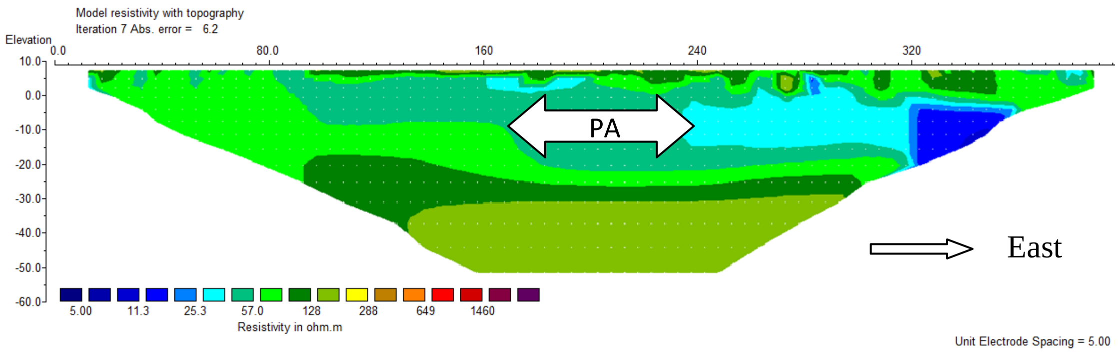
Figure 5.10. Geoelectrical model of line A205.

Line A206

Line A206 was located between a small road and an artificial drainage system in a west-east direction. The site was surrounded by a paddy field with elevation of 9 m above mean sea level. Kelantan River was found around 800 m to the west of this site.

In the geoelectrical model (Figure 5.11.), an average resistivity value of around 100 ohm.m is observed near surface. However, at some places lower resistivity value (30-50 ohm.m) coloured as light blue and greyish green are observed, indicating more porous materials with higher moisture content.

At depth ranging from -6 to -21 m, a low resistivity value (30 - 60 ohm.m) is obtained corresponding to the potential aquifer. In particular, a relatively lower resistivity value of less than 12 ohm.m appears in the eastern side of the line. Discussion regarding this matter (lower resistivity value) is presented in the next subchapter (5.3).



PA = Potential aquifer

Figure 5.11. Geoelectrical model of line A206.

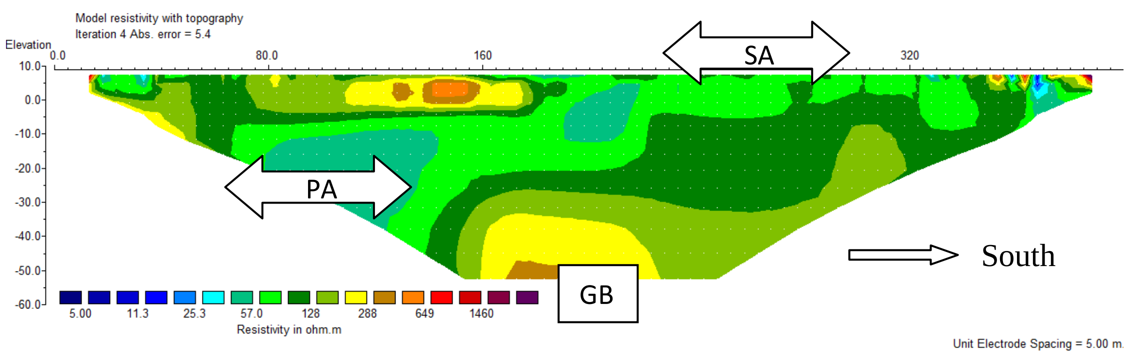
Line A207

The survey line A207 was conducted adjacent to the artificial drainage system with elevation of 9 m above mean sea level. The line direction was from north to south.

In the geoelectrical model (Figure 5.12.), a change of relatively higher (600 ohm.m) to lower (80 ohm.m) resistivity value occurs at a depth ranging from 7 to -3 m. This corresponds to changes of less porous material to a more porous one. The boundary can be seen below the 180 m mark. The resistivity value coloured as light green (about 80 ohm.m) dips below the 270 m mark at a depth of -1 to -41 m below the 70 m mark. This corresponds to the porous material, where at this zone the shallow aquifer and the deeper aquifer are connected to each other. This zone is probably an ancient river channel. At this survey site, the river shifting occurs from the east to the west and develops a new channel (Chapter 2.5.3), as reported by Koopmans (1972).

Wells WA204 and KB39 exist around 300 m from the survey line. Based on water chemical analysis results (Table 5.1) in both wells, the groundwater samples indicate fresh water characteristics.

At depth deeper than -47 m in the section, the geoelectrical resistivity indicates the geological contact between the Quaternary basinal clastic sediments and the pre-Quaternary bedrock. It is marked by a resistivity value of around 350 Ohm.m. Finally, the top of high resistivity zone (>350 ohm.m) is an irregular topography of the pre-Quaternary bedrock.



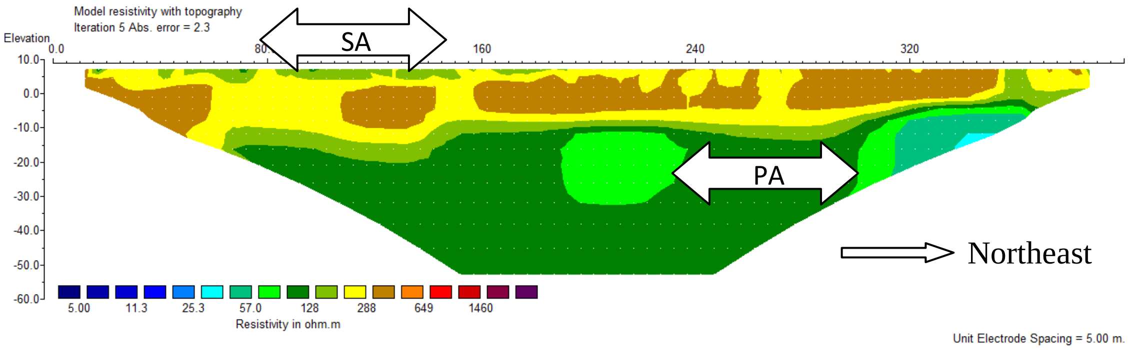
PA = Potential aquifer; GB = Granite bedrock; SA = Shallow aquifer

Figure 5.12. Geoelectrical model of line A207.

Line A208

A paddy field (9 m above mean sea level) was chosen to perform survey line A208. The line was laid on small road soulder in a southwest-northeast direction. Puddle of water was about 30 cm below the ground surface.

In the geoelectrical model along line A208 (Figure 5.13), more compacted material with resistivity value of about 300 ohm.m is observed and dipped to a south-west direction. It begins from the surface level at 340 m mark to a depth of -3 m below 0 mark. However, a lower resistivity value (about 120 ohm.m) is obtained near surface to a depth of around 4 m from 0 - 180 m mark corresponding to the shallow aquifer. At a depth from about -11 to -30 m, there is a potential aquifer existed with resistivity value of about 50 ohm.m. In this section, the lowest resistivity value is 37.35 ohm.m. However the basement existence is not recorded in the section.



PA = Potential aquifer; SA = Shallow aquifer

Figure 5.13. Geoelectrical model of line A208.

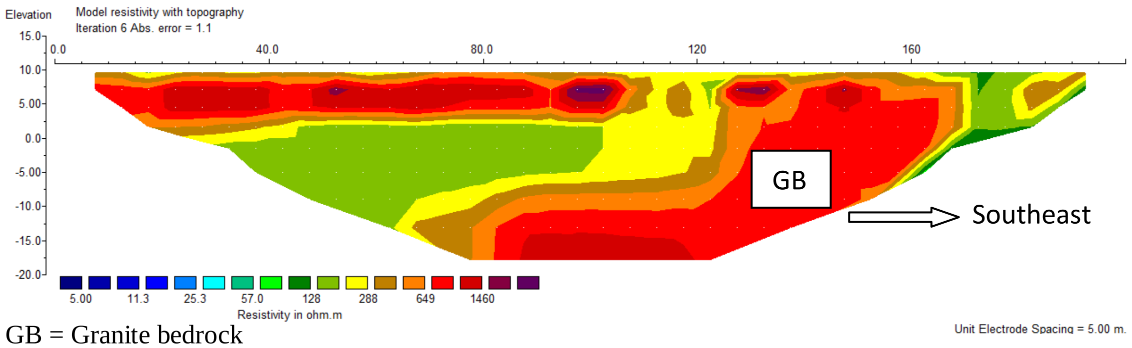
Line A209 and Line A210

Bukit Marak is a hill in the area of Kelantan River delta where the line A209 and line A210 were located. The survey line A209 and line A210 were performed on the foot hill at northwestern and southeastern respectively. Many granite outcrops were found in the surrounding hill (Figure 5.14.A,B). The geoelectrical resistivity surveys were performed on the road side when small to moderate spots raining occurred. The hill peak was in the southeast of the line survey (A209).

In the geoelectrical model along line A209 (Figure 5.15), relatively higher resistivity values (more than 600 ohm.m) can be clearly seen at zone coloured red. The red features are believed wet weathered granite boulder. The soil in the surrounding boulder was fully saturated by rainwater. Direct resistivity measurements were done at five points on the soil surface with average of 278.28 ohm.m and standard deviation of 20.35 ohm.m. The measurement was also done for weathered surface of granite boulder, and the average values for this measurement was 1878.17 ohm.m with standard deviation of 118.53 ohm.m. Overall, it can be noticed that the body of granite dipping to the northwest.

A low resistivity value (120 ohm.m) occurs from a zone of 165 m mark and 185 m mark, corresponds to more porous and more permeable material. At this zone, the surface water is possible entering to deeper aquifer directly. The possibility of water accumulation in a depth of around -4 m appears with the resistivity value of 70 ohm.m.

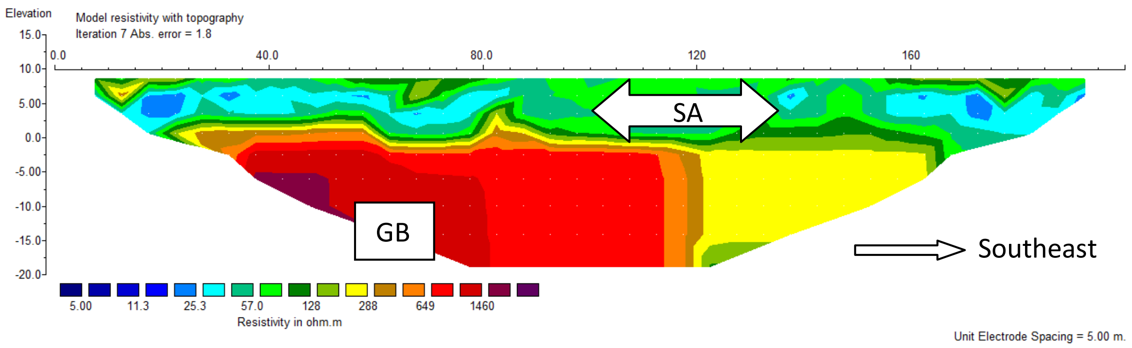
Figure 5.14. View of Marak Hill where Geoelectrical model of line A209 and line A210 were conducted (A). Outcrop of granite body before raining (B).



GB = Granite bedrock

Figure 5.15. Geoelectrical model of line A209.

In geoelectrical model along line A210 (Figure 5.16), relatively lower resistivity value is observed at a depth of 2 m from northwestern to 6.5 m at nortwestern. This corresponds to the shallow aquifer. The aquifer extends to southeast as the granite body dips to southwestern. The aquifer thickness increases from 4 m thick in the southwest to around 7 m thick at the southeast. A relatively higher resistivity value (>400 ohm.m) possibly granite is observed from a depth of 2 m at the northwestern and dips to the souteastern.



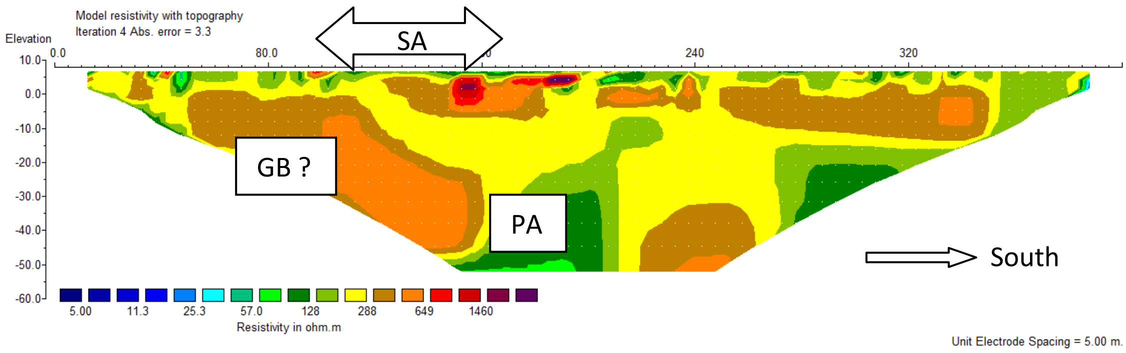
GB = Granite bedrock; SA = Shallow aquifer

Figure 5.16. Geoelectrical model of line A210.

Line A211

The site for line A211 was located around a paddy field area with an elevation of 8 m above mean sea level. The line was in a north-south direction. The paddy field was puddle by water from 30 cm below the ground surface. Bukit Marak hill was found around 1.9 km to the east of the line.

In the geoelectrical model (Figure 5.17), relatively lower resistivity values (100 ohm.m) are observed from near the surface to around a depth of 3 m. The values correspond to shallow freshwater aquifer. This is based on well WA209 which was located around 150 m from the survey line with 6 m depth indicate fresh water aquifer (Table 5.1). A resistivity value coloured as green is observed at depth below than -17 m. This value probably corresponds to potential freshwater aquifer. The higher resistivity values of around 400 ohm.m are interpreted as representing the weathered granite.



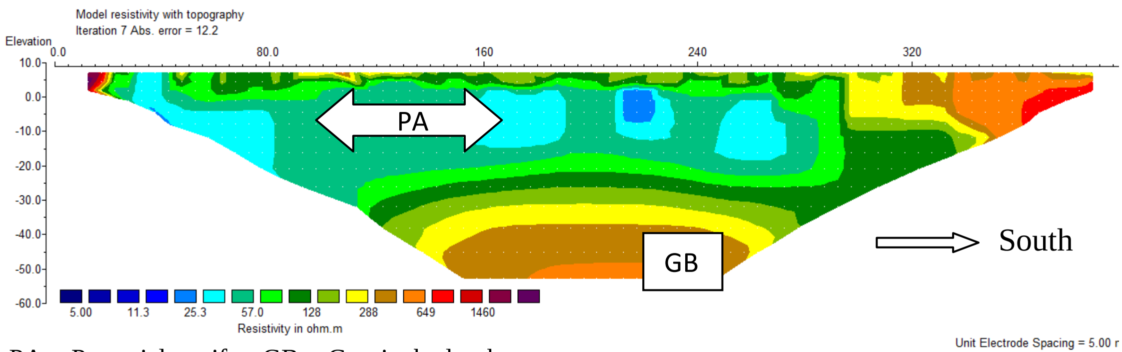
GB= Granite bedrock; PA= Potential aquifer; SA = Shallow aquifer

Figure 5.17. Geoelectrical model of line A211.

Line A212

Line A212 was located on a site of 9 m above mean sea level. The survey line was laid in between a minor road and an artificial drainage system. The survey site was surrounded by a rubber trees plantation. Water in the drainage system was around less than 2 m below the ground surface.

A relatively higher resistivity value of more than 2000 ohm.m is obtained at zone up to 20 m mark location along the line (Figure 5.18), correlating to the concrete of minor bridge. Below 30 - 40 m mark position, a lower resistivity value (about 30 ohm.m) is observed an indication of a link between surface water and the deeper aquifer. A resistivity value of around 20 - 70 ohm.m is observed in between 2 to -21 m. This corresponds to the potential freshwater aquifer. Relatively higher resistivity value (>400 ohm.m) can be found at depth of below than -31 m, corresponding to the pre-Quaternary bedrock.

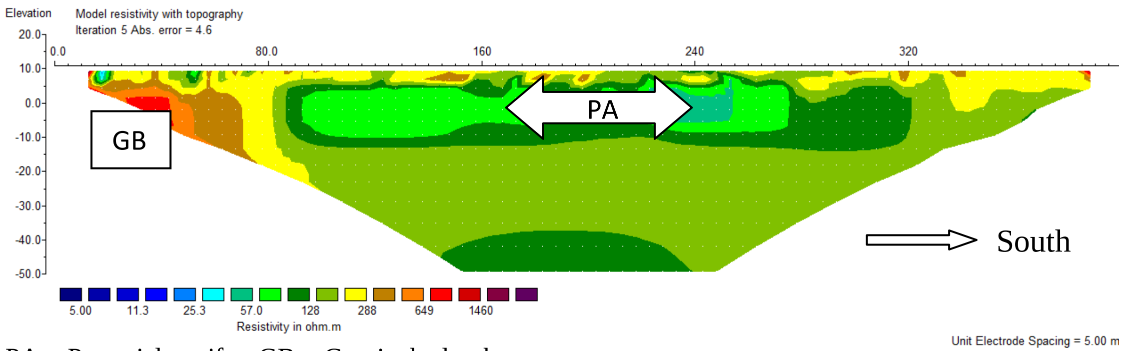


PA = Potential aquifer; GB = Granite bedrock;

Figure 5.18. Geoelectrical model of line A212.

Line A213

The geoelectrical resistivity survey for line A213 was performed at a site surrounded by a paddy field with an elevation of 11 m above mean sea level. The line was in a north-south direction. In the geoelectrical model along line A213 (Figure 5.19.), an average resistivity value of around 180 ohm.m is observed near the surface, corresponding to the wet clay material. The values were also similar to the data of direct resistivity measurements. Relatively lower resistivity value of about 70 ohm.m can be found in the region of 80 m mark at 4 to -9 m depth. This corresponds to possibly of a potential freshwater aquifer. WA212 is the nearest well to the survey line in which the chemical analysis result indicates freshwater characteristics. In areas below -39 m depth, a relatively lower resistivity value (100 ohm.m) is obtained corresponding to a deeper aquifer. Relatively higher resistivity value of more than 600 ohm.m can be observed as a granite basement, starting from a depth of below 1 m at the beginning of the survey line to 50 m mark position.



PA = Potential aquifer; GB = Granite bedrock

Figure 5.19. Geoelectrical model of line A213.

Line A214

Line A214 was located in a rubber tree plantation. The survey was conducted on the road shoulder (12 m above mean sea level) in a northeast-southwest direction. There was no information about depth of water level in this site.

In the geoelectrical model of line A214 (Figure 5.20.), higher resistivity value of around 450 ohm.m is observed near the surface corresponding to the embankment material. Relatively lower resistivity value of about 20 ohm.m is obtained at depth of around 2 to - 23 m in northeastern part. The resistivity value increases to about 70 ohm.m in southwestern. These resistivity values however are interpreted as potential freshwater aquifer. The nearest well of this site is WA208, shows freshwater aquifer characteristics based on chemical analysis. There is no granite basement observed in the geoelectrical model along of A214.

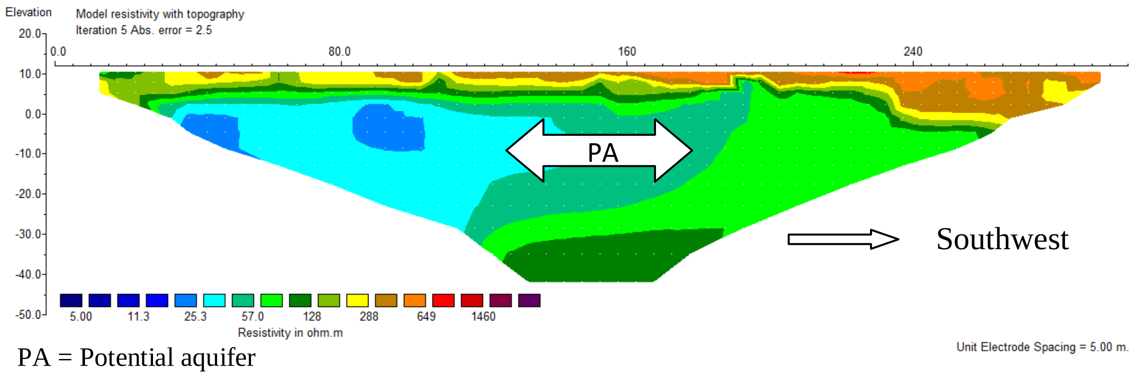
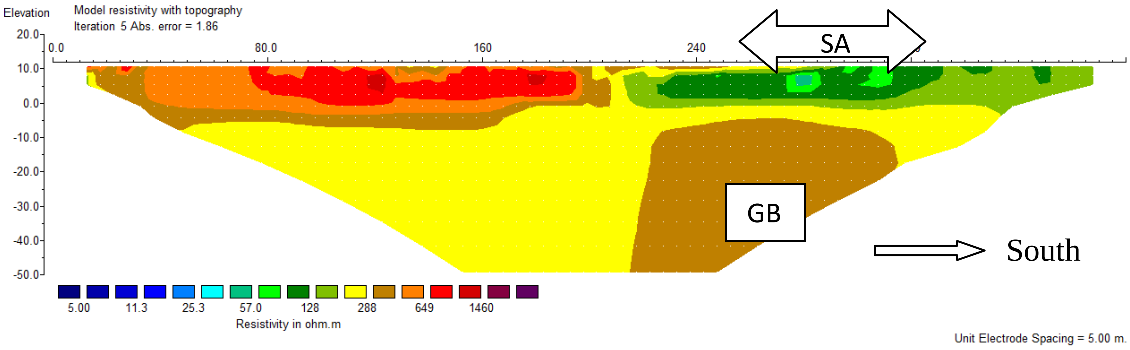


Figure 5.20. Geoelectrical model of line A214.

Line A215

A site 2 km to the landward from the line A213 was selected to locate line A215. The survey line was performed beside an artificial drainage system with elevation of 12 m above mean sea level. The line was in a north-south direction and lied within the area around rubber trees plantation. Depth to water level was around 50 cm from the ground surface in the drainage system.

A relatively higher resistivity value (about 300 ohm.m) is observed near surface at the northern part of the line (Figure 5.21). A relatively lower resistivity value (around 150 ohm.m) is detected towards the south. At a depth of around 10 to 2 m, the resistivity values reduced from about 550 ohm.m in the north to about 100 ohm.m in the south indicating the presence of more compact, less porous and less permeable material in the north. On the other hand, more porous material containing freshwater is obtained in the southern part of the line. Unfortunately, there was no well existed around this site for comparison. Resistivity become higher in southern part at depth of -3 m.



GB = Granite bedrock; SA = Shallow aquifer

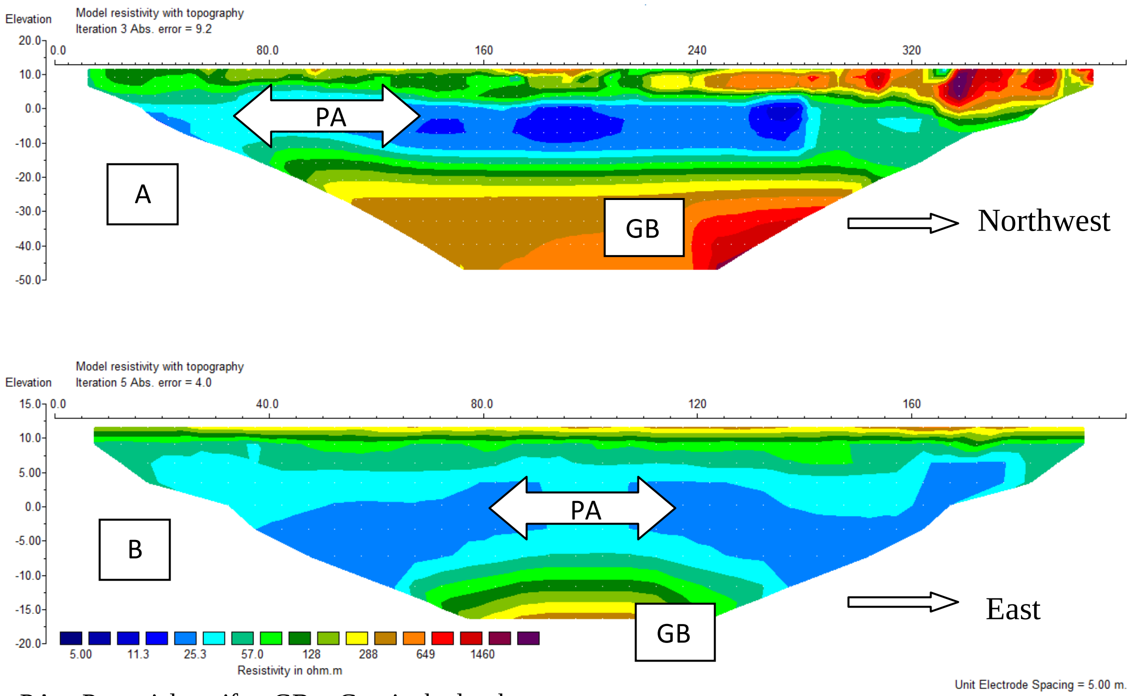
Figure 5.21. Geoelectrical model of line A215.

Line A216 and A217

The next two survey lines, line A216 and A217 were located in a paddy field. The line A216 used 61 electrodes with 400 m length, meanwhile the line A217 was conducted using 41 electrodes with 200 m length.

In the geoelectrical model along line A216 (Figure 5.22.A), resistivity value ranging from 13–100 ohm.m is revealed at a depth starting from 5 to - 15 m. This indicates the possibility of an aquifer in this depth interval. Unfortunately, no water sample was derived from this site. At the depth from -22 m down, relatively higher resistivity values of more than 400 ohm.m are observed, corresponding to the pre-Quaternary bedrock.

In the geoelectrical model along line A217 (Figure 5.22.B), an average of near surface resistivity value of about 250 ohm.m is obtained corresponding to clay with low moisture content. The values do not have big differences compared to the direct surface resistivity measurement (296.15 ohm.m of its average). At the depth of around 8 to -12 m, the resistivity values range from 17 ohm.m (the minimum value) to around 60 ohm.m, corresponds to the zone with freshwater-bearing more porous formation (potential aquifer). Depth below than -15 m more compacted material is obtained correlating to the pre-Quaternary bedrock.



PA = Potential aquifer; GB = Granite bedrock;

Figure 5.22. Geoelectrical model of (A) line A216 and (B) line A217.

Line A218

Perol is the name of a pumping well station which supplies domestic water of 1.2 million litres per hour for surrounding area until Machang area. Unfortunately, around the wells, there was no space for conducting geoelectrical resistivity survey. The nearest location 800 m from the pumping well station was used to survey line A218. The site was surrounded by rubber trees plantations adjacent to the small dead river. Depth to puddles of water in the dead river was around 3 m from the ground surface.

This site was 11 m above mean sea level. It was situated more or less 6.5 km from the nearest bank of the Kelantan River and 20.2 km from the nearest beach line. At the Perol pumping well station, there are 4 production wells and 2 monitoring wells. Figure 5.23 shows subsurface lithology derived from gamma ray interpretation. According to drilling information, basement was at a depth of 44 m in this site.

In the geoelectrical model along line A218 (Figure 5.23.), a dominant resistivity values of aabout 400 ohm.m is observed near surface to about 6 m depth. This correlates to the clayey sand soil with very low moisture content. Furthermore, moisture content on the surface was apparently low. A relatively higher resistivity value (about 1000 ohm.m) is observed at a depth zone ranging from 7 m to 2 m. Based on gamma ray log interpretation, clay with sandy soil can be found within this zone. At the next depth, lower resistivity value of less than 15 ohm.m is observed in the zone ranging from 12-25 m (-1 to -14m) depth corresponding to the potential aquifer. High resistive feature (more than 400 ohm.m) can be recognised in the model from the depth of -34 m downward. This feature corresponds to the pre-Quaternary bedrock.

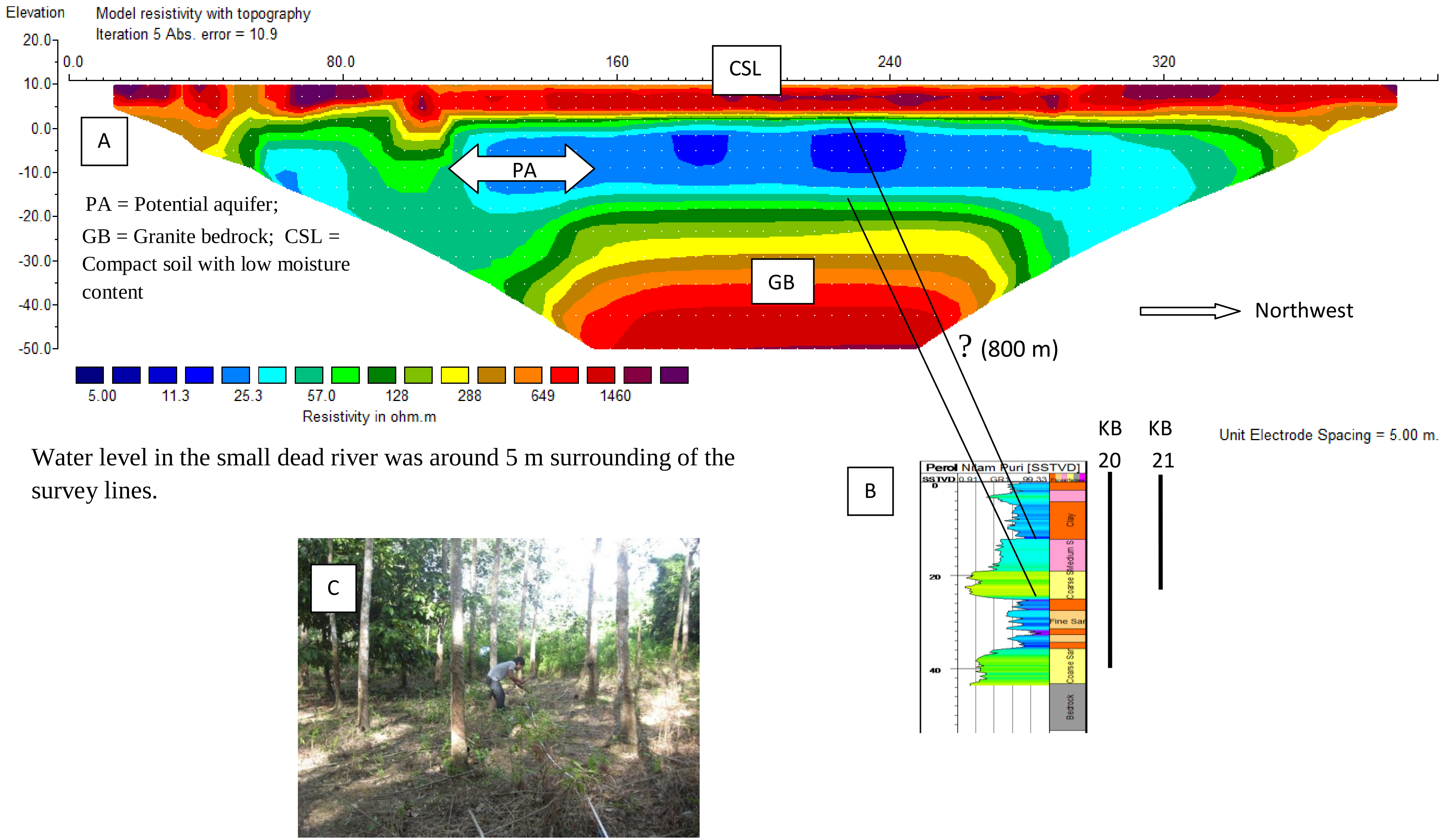
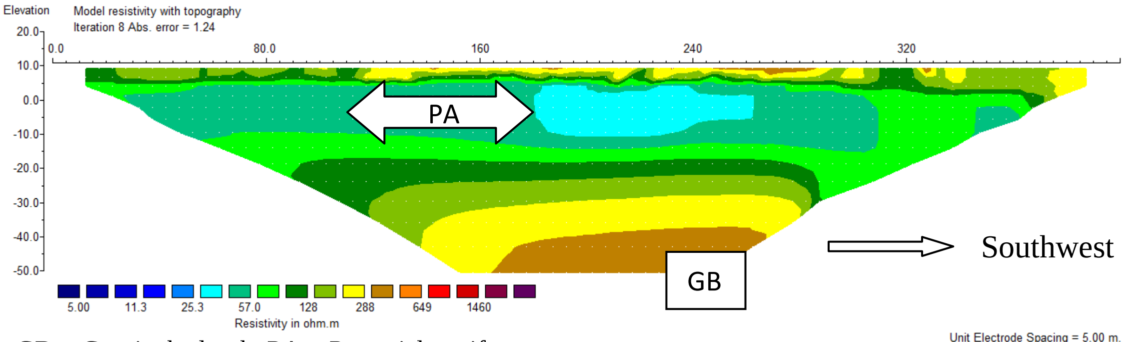


Figure 5.23. (A) Geoelectrical model of line A218. (B) Gamma ray interpretation of Perol well station. (C) A view around line A218

Line A219

The line A219 was located at a site around a paddy field with elevation of 11 m above mean sea level. The survey was performed exactly between a drainage system and a minor road. It was about 1.8 km to southwest from the Perol pumping well station which has a northeast-southwest direction.

In the geoelectrical model (Figure 5.24), an average resistivity value of 180 ohm.m is obtained near surface, corresponding to moderately dried clay material. A lower resistivity value (30-80 ohm.m) occurs at depth from 3 to -13 m. This correlates to the potential sandy aquifer. Unfortunately, no existing well was found the surrounding survey site. Relatively higher resistivity value (>400 ohm.m) appears from the depth of -37 m downward. This correlates to the granite basement according to the nearest Perol Borehole.



GB = Granite bedrock; PA = Potential aquifer

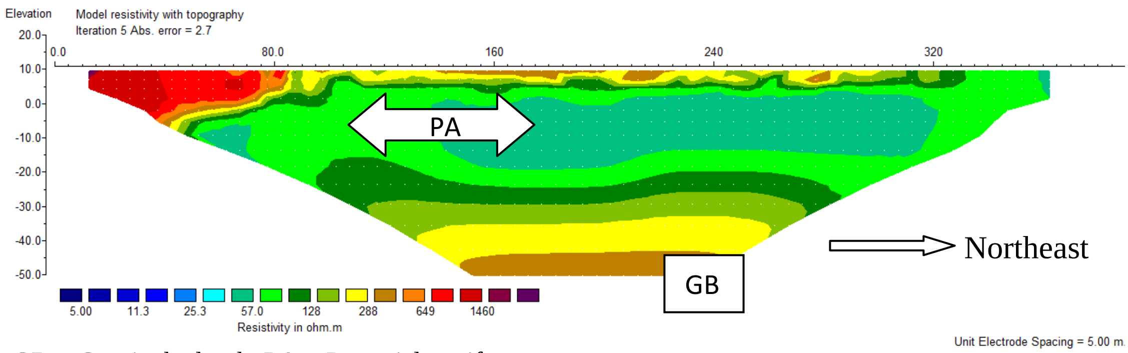
Figure 5.24. Geoelectrical model of line A219.

Line A220

The line A220 was located at an area of all-round a paddy field with elevation of 11 m above mean sea level. The survey was performed exactly between a drainage system and a minor road with in a northeast-southwest direction.

In the geoelectrical model along line A219 (Figure 5.25), an average resistivity value of around 200 ohm.m is observed near surface, indicating moderately dried clay material. From the 330 m mark to the northeast ward, relatively lower resistivity value (about 65 ohm.m) is observed corresponding to the more porous sandy material. This zone can be a direct access for water from surface to the aquifer.

The possibility of potential aquifer is obtained at a depth ranging from 3 to -13 m with resistivity value range from 50 - 100 ohm.m. Well WA211 is the nearest well existed in this site. The water chemical result indicates that the aquifer has fresh water characteristics. In the section, relatively higher resistivity value (>400 ohm.m) from a depth of -43 m down is interpreted as granite basement based on Perol borehole.



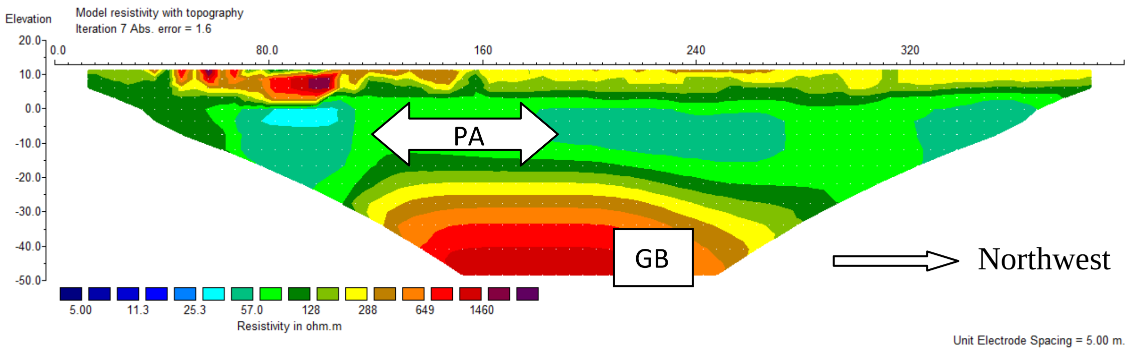
GB = Granite bedrock; PA = Potential aquifer

Figure 5.25. Geoelectrical model of line A220.

Line A221

Line A221 was located 13 m above mean sea level in between an artificial drainage system and a paddy field. The line was in a southwest-northeast direction. A puddle of water was measured about 1 m below the ground surface.

In the section of line A221 (Figure 5.26), an average resistivity value of 200 ohm.m was observed near surface, corresponding to clayey sand soil with moderate moisture content based on borehole. Starting from a depth of around 7 to -12 m, the possibility of potential aquifer is encountered with resistivity value of about 40 ohm.m. The nearest well, WA210, shows the freshwater characteristic existed within the aquifer. Relatively higher resistivity values of more than 400 ohm.m exist from a depth of -21 m downward. This correspond to the pre-Quaternary bedrock. The granite basement is noted dipping in a northeast direction.



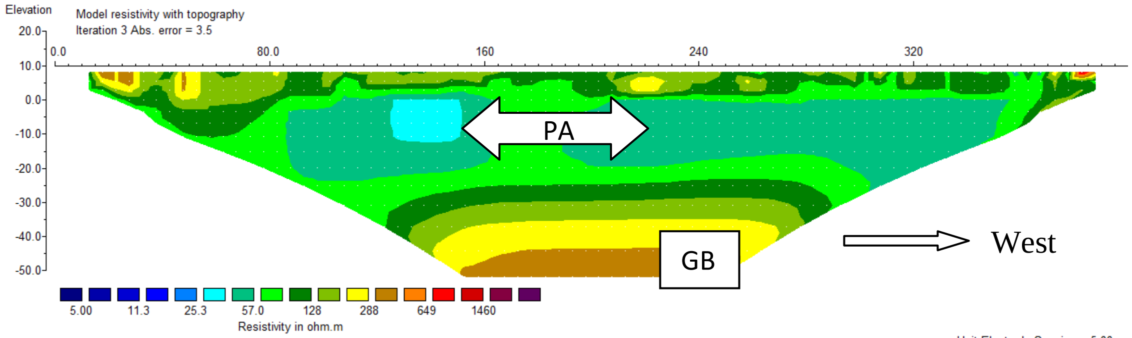
GB = Granite bedrock; PA = Potential aquifer

Figure 5.26. Geoelectrical model of line A221.

Line A222

Line A222 was located in a paddy field 10 m above mean sea level. The line was laid beside a small road in east-west direction. A puddle of water in the paddy field was around 30 cm from the ground surface.

In the geoelectrical model of line A222 (Figure 5.27), an average resistivity value of around 130 ohm.m occurs near surface which corresponds to clay material with moderate moisture content. Resistivity value of about 30 - 80 ohm.m is observed at the depth ranging from 2 to -14 m, indicates potential aquifer. The nearest well (WA216) is located at 200 m away from the site. Hydrogeochemical results indicate freshwater characteristics existed within the aquifer. Relatively higher resistivity value (>400 ohm.m) can be recognized at depth below than -40 m. This corresponds to pre-Quaternary bedrock.



GB = Granite bedrock; PA = Potential aquifer

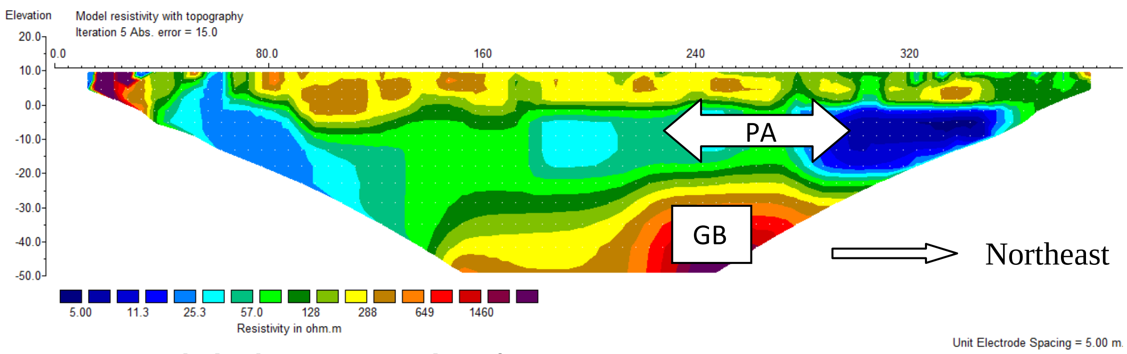
Figure 5.27. Geoelectrical model of line A222.

Line A223

The line A223 was located at a site with a paddy field on the east and rubber tree plantation on the west. The survey line was exactly between an artificial drainage system and minor road with an elevation of 11 m above mean sea level. A puddle of water was about 1.2 m below the ground surface in the drainage system.

Relatively higher resistivity depth (around 200 ohm.m, coloured yellow) are observed near surface at 70-250 m mark (Figure 5.28.). This zone correlates with more less porous material. Relatively high resistivity value (>1500 ohm.m) is obtained at the beginning of survey line correlating to the small bridge concrete. Below than -1 m to -11 m depth, the zone coloured light blue (about 12 ohm.m) can be obtained at the northeast and southwest. The value is similar to a contaminated aquifer with light brackish water content (Chapter 6). For comparison, the other lines A203, A207 and A208, which are closer to the beach, do not show the lower anomaly as shown in line A223, which means that light brackish water content within the aquifer is almost impossible. Furthermore, there is no brackish water indication within Area 2 (Table 5.1). The anomalies such as in line A223 also can be found in the lines of A201, A202, A204, A205, A206, A214, A216, A217 and A218. In order to find the cause of the anomaly, the new well (WA2) was drilled at this site. The detailed discussion regarding this matter (low resistivity anomaly) will be presented in the next subchapter.

A higher resistivity value of more than 400 ohm.m is obtained at the northeastern from the depth of -22 m downward. This correlates to the granite bedrock. The granite bedrock is tilted toward the southwest.



GB = Granite bedrock; PA = Potential aquifer

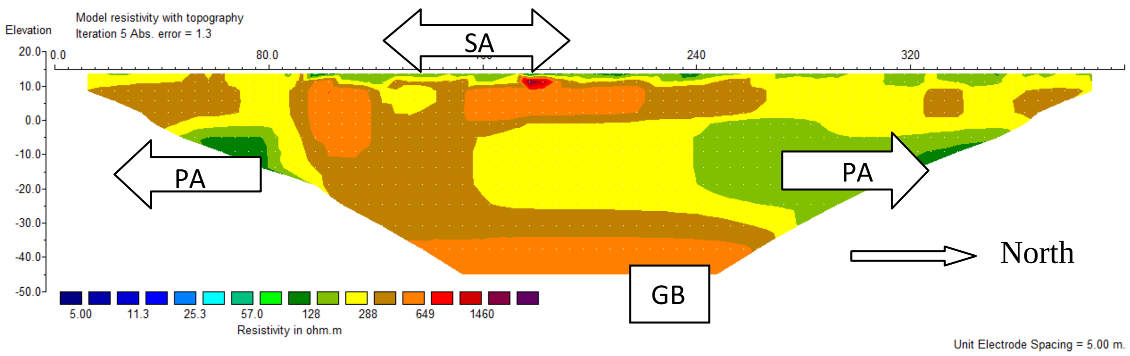
Figure 5.28. Geoelectrical model of line A223.

Line A224

The geoelectrical survey for line A224 was carried out at a site around 4 km away west of the line A213. The site was surrounded by a paddy field and a rubber trees plantation elevation of 15 m above mean sea level. The line was laid in a south-north direction beside an artificial drainage system. The water in the drainage system was around 80 cm below the ground surface.

An average resistivity value of 230 ohm.m appears near surface from 0 up to 90 m mark, corresponding to clay material with low moisture content (Figure 5.29.). Relatively lower resistivity value (~120 ohm.m) is observed from surface to a depth of about 9 m from 90-250 m mark. This corresponds to shallow sandy aquifer. The well WA214 was located 250 m away from the survey line. The chemical result from the well indicates freshwater characteristics.

Relatively higher resistivity value (~300 ohm.m) is obtained at a depth ranging from around 9 to 5 m, corresponding to less porous material. Again, relatively lower resistivity value (around 130 ohm.m) appears at depth around 13 m to 28 m. This correlates with to the potential aquifer. A higher resistivity value of more than 400 ohm.m reveal at depth from -35 m down which corresponds to the granite basement.



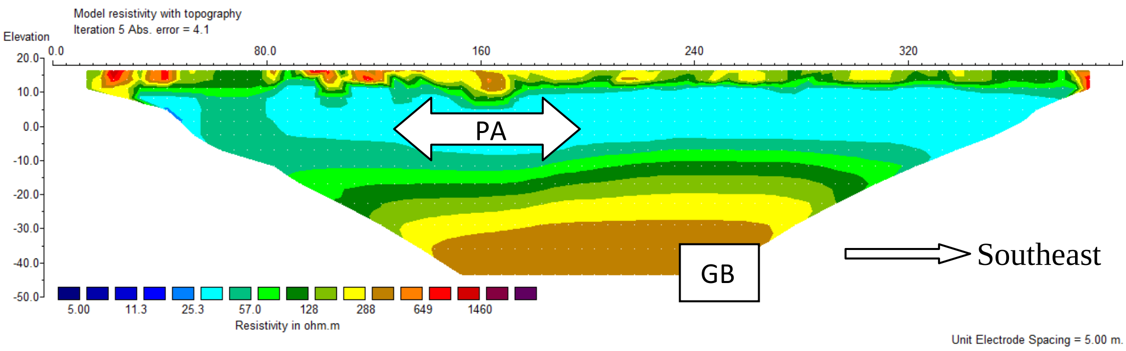
GB = Granite bedrock; PA = Potential aquifer; SA = Shallow aquifer

Figure 5.29. Geoelectrical model of line A224.

Line A225

The survey line A225 was conducted at a site 3 km to the northwest from the line A224. The site was surrounded by a rubber trees plantation with elevation of 18 m above mean sea level. The line was laid in a northwest-southeast direction beside an artificial drainage system. A puddle of water in the drainage system was around 1.6 m below the ground surface.

In the geoelectrical model along line A225 (Figure 5.30.), an average resistivity value of about 200 ohm.m is observed near surface corresponds to the clay material with moderate moisture content. Relatively lower resistivity value (35 ohm.m) is obtained at the depth ranging from 11 to - 6 m that indicates the potential aquifer. The well WA213 is located around 200 m from the survey line to the northeast which the chemical result shows fresh water characteristics. A higher resistivity value of more than 400 ohm.m reveals at the depth from -21 m downward which corresponds to the granite basement.



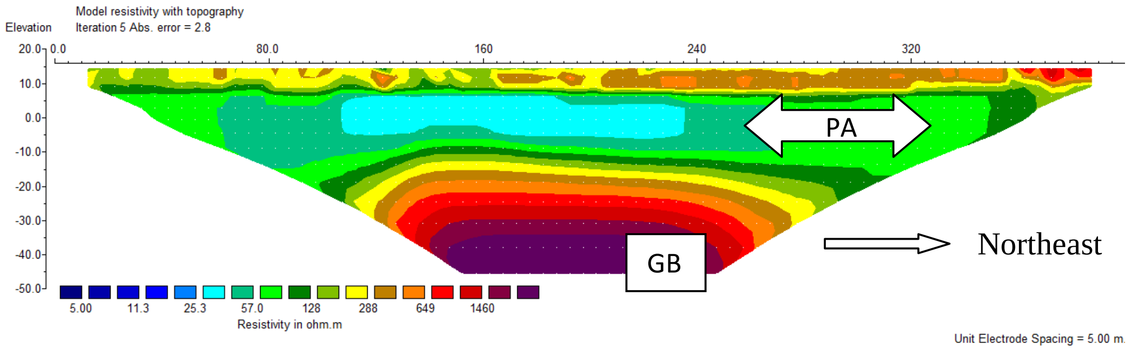
GB = Granite bedrock; PA = Potential aquifer

Figure 5.30. Geoelectrical model of line A225.

Line A226

A site surrounded by a rubber trees plantation and a paddy field was chosen to survey line A226. The site has elevation of 16 m above mean sea level. The survey line was performed in a southwest-northeast direction and laid beside an artificial drainage system. The water in the drainage system was around 1.6 m below the ground surface.

In the geoelectrical model along line A226 (Figure 5.31.), resistivity value of about 200 ohm.m is observed near surface. This corresponds to clay material with moderate moisture content. Relatively lower resistivity value (about 30-100 ohm.m) dominates at a depth from around 10 to -5 m, correlates to the potential aquifer. The well WA217 is located approximately 200 m from the survey line to the northwest. The water chemistry results show fresh water characteristics in the groundwater samples. The higher resistivity value of more than 400 ohm.m is obtained at depth below than -18 m corresponding to the pre-Quaternary basement bedrock.



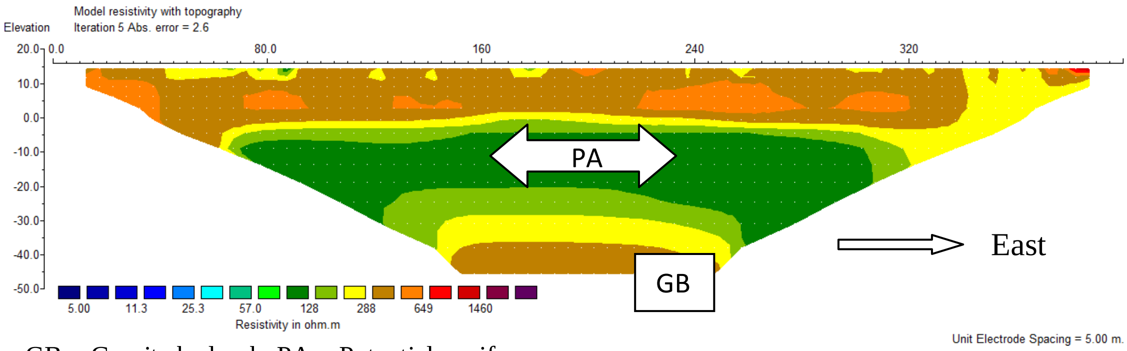
GB = Granite bedrock; PA = Potential aquifer

Figure 5.31. Geoelectrical model of line A226.

Line A227

The last geoelectrical resistivity survey conducted in Area 2 was line A227. It was performed at a site adjacent to the border of Area 1 and Area2 and surrounded by a rubber trees and a paddy field. This line was in a west-east direction and laid beside an artificial drainage system with elevation of 16 m above mean sea level. A puddle of water in the drainage system was observed around 1.6 m below the ground surface.

In the geoelectical model along line A227 (Figure 5.32), an average resistivity value of about 250 ohm.m was observed near the surface. It corresponds to clayey sand soil material with moderate moisture content. Shallow aquifer is observed from the surface until 11 m depth at several places with resistivity value of around 150 ohm.m. Relatively lower resistivity value (120 ohm.m) can be found at a depth interval of -2 to -24 m. This correlates to potential aquifer. The well WA218 is located approximately 200 m from the survey line to the northeast which indicate fresh water characteristics in the groundwater. Relatively higher resistivity value with more than 400 ohm.m reveals from depth of -36 m down ward which corresponds to the pre-Quaternary basement.



GB = Granite bedrock; PA = Potential aquifer

Figure 5.32. Geoelectrical model of line A227.

5.2.3. Resistivity Distribution

In this area, the relatively high resistivity contrast between the Quaternary basinal clastic sediments and the pre-Quaternary bedrock are used to extract geological information in term of basin feature. Tracing the geometry of the pre-Quaternary bedrock and potential aquifer are also possible.

Figure 5.33 represents a depth of model is not reduced to sea level. The same procedure as Subchapter 4.3 is used to obtain this figure. The shallowest basement (less than 5 m, coloured light green) is found closer to the Marak Hill and its depth increases to southwest direction. A lot of exposed granite was found in area around Marak Hill. The basement dips gently from the Marak Hill to southwest and creates more slopes to the northwest. The deepest basement zone is represented by blue colour which is found in the area around Pintu Geng well station (northeastern part). Around this part, geoelectrical resistivities do not show any basement indication. It is due to the deepest depth that can be reached by geoelectrical model was only 60 m. The data input (basement depth) for Pintu Geng well station was obtained from well drilling information. While, in the southern part, basement bedrock is at depth of 20-30 m. Generally, basement bedrock dips from the south to the north.

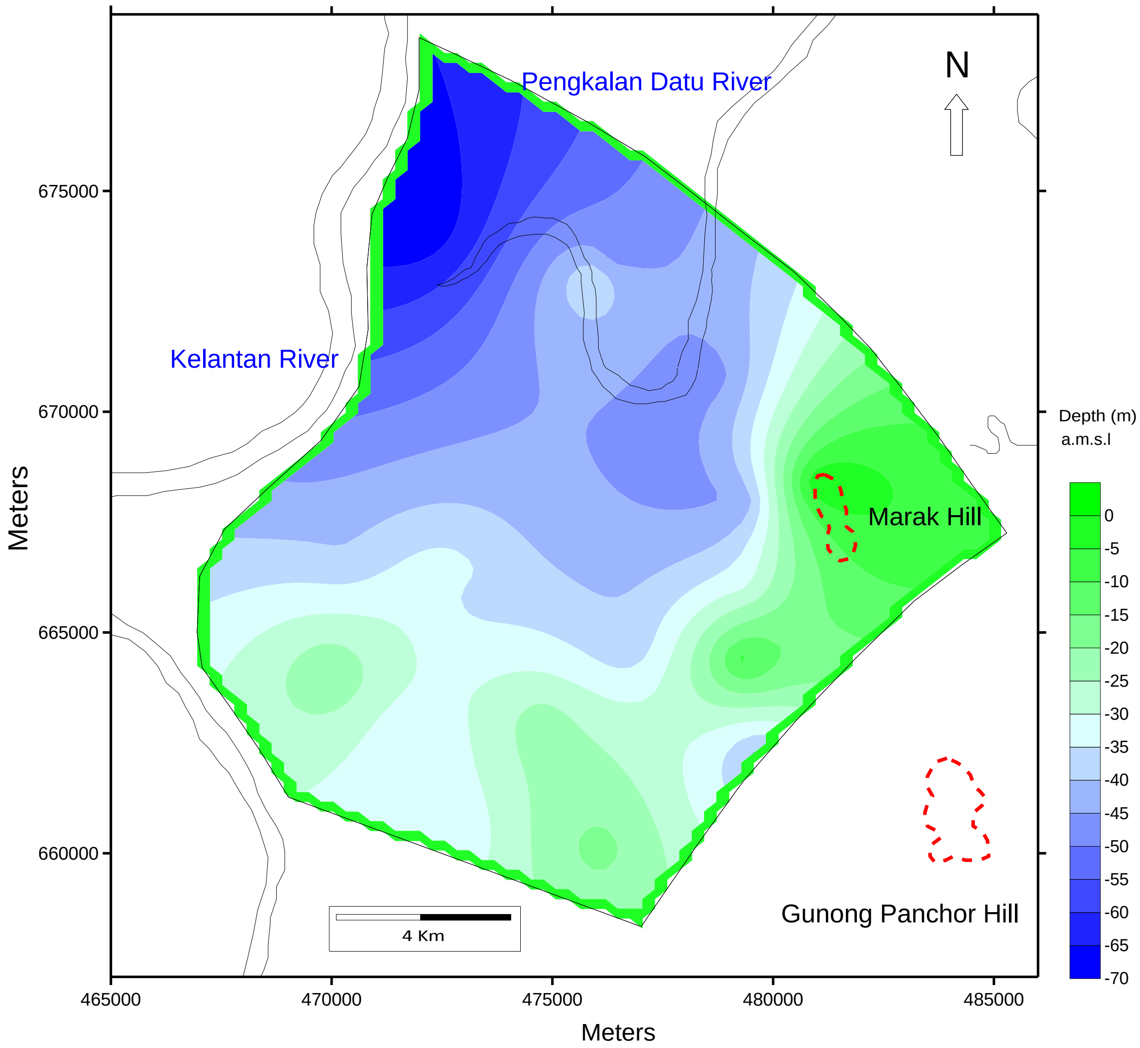


Figure 5.33. Granite basement map of Area 2 (relative to mean sea level) derived from interpretation of geoelectrical model.

In the entire geoelectrical models for deeper zone, the patterns of high resistivity values clearly define the shape of the pre-Quaternary bedrock. From the depth of basement interpretation, the thickness of fluvial deposit can be retrieved. Finally, the thickness of fluvial deposit inferred from geoelectrical resistivity survey is around 5-10 m at the eastern part (around Marak Hill), 30-35 m in the south and 50-80 m at the northern part.

A simplified depth slice of resistivity distribution for Area 2 is given in Figure 5.34. The same procedure in subchapter 4.3 is used to produce this resistivity depth slice. In the figure the relatively higher surface resistivity value of about 400 ohm.m reveal at the site around Marak hill and at Sungai Mati in Perol area. The shallow aquifer is generally found at depth of 5 m above mean sea level with resistivity value ranging from 100 - 150 ohm.m.

The relatively lower resistivity value of less than 15 ohm.m coloured as blue can be found at depth of 0 - 25 m. This lower resistivity value is extended from southeast to northwest. It appears from 0 m at the southeastern and dips to the northwestern. The lower value seems to be covering much larger area as move to the northwest in the deeper depth (-5 m). The largest covering area can be obtained at the depth of -10 m. In the deeper depth (-15 m), the lower values are smaller and gradually disappear at the southeastern. Finally, it only can be found at the depth -25 m at the northwestern.

Detailed discussion regarding to the lower resistivity anomaly is discussed in the next subchapter. The cross section geological model of the subsurface derived from interpretation of the geoelectrical resistivity data for both Area 2 and Area 3 is presented in Chapter 6.

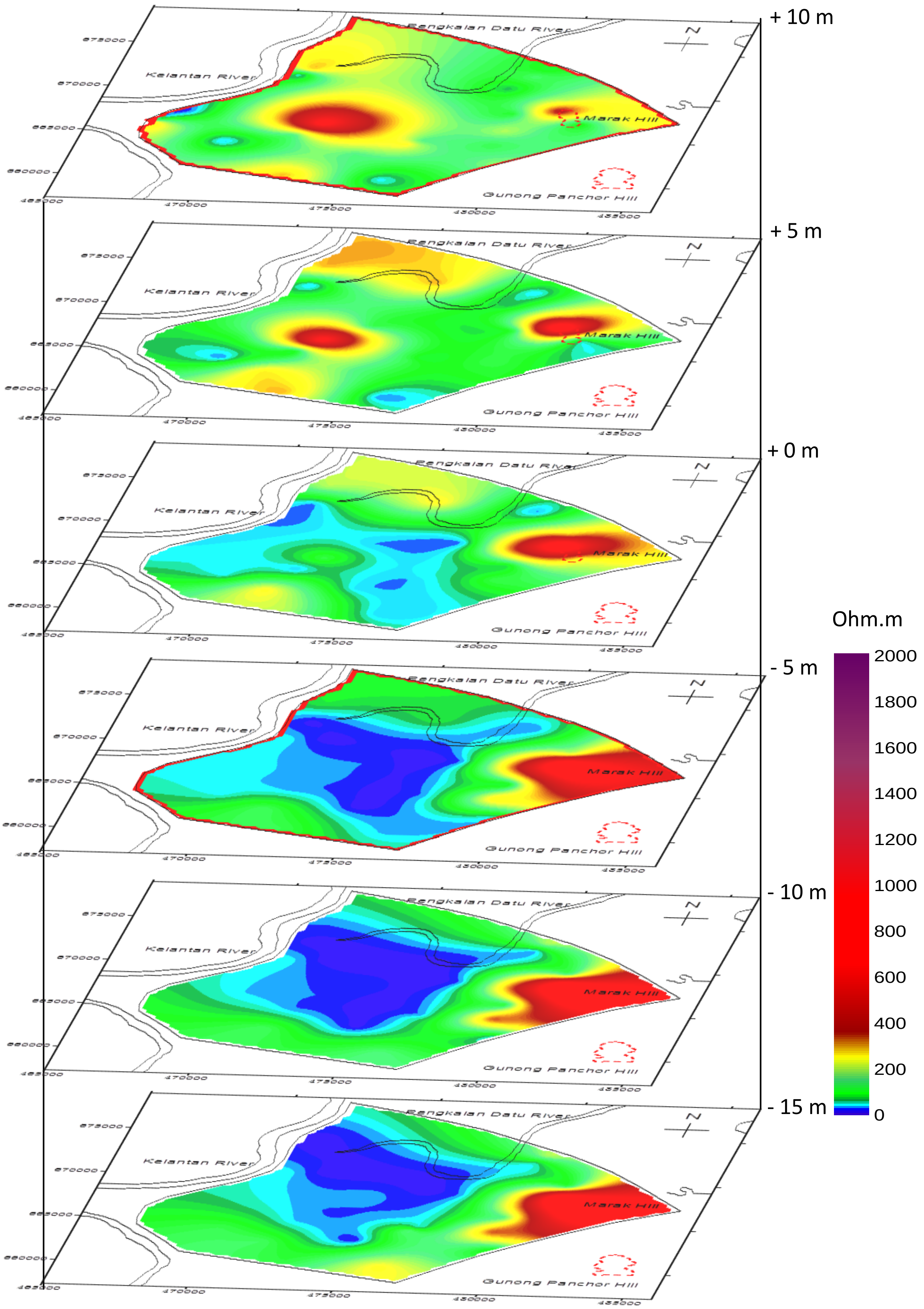


Figure 5.34. Depth slice resistivity distribution. Higher resistivity value appears around Marak Hill, whilst relatively lower resistivity value makes a trend from south to north.

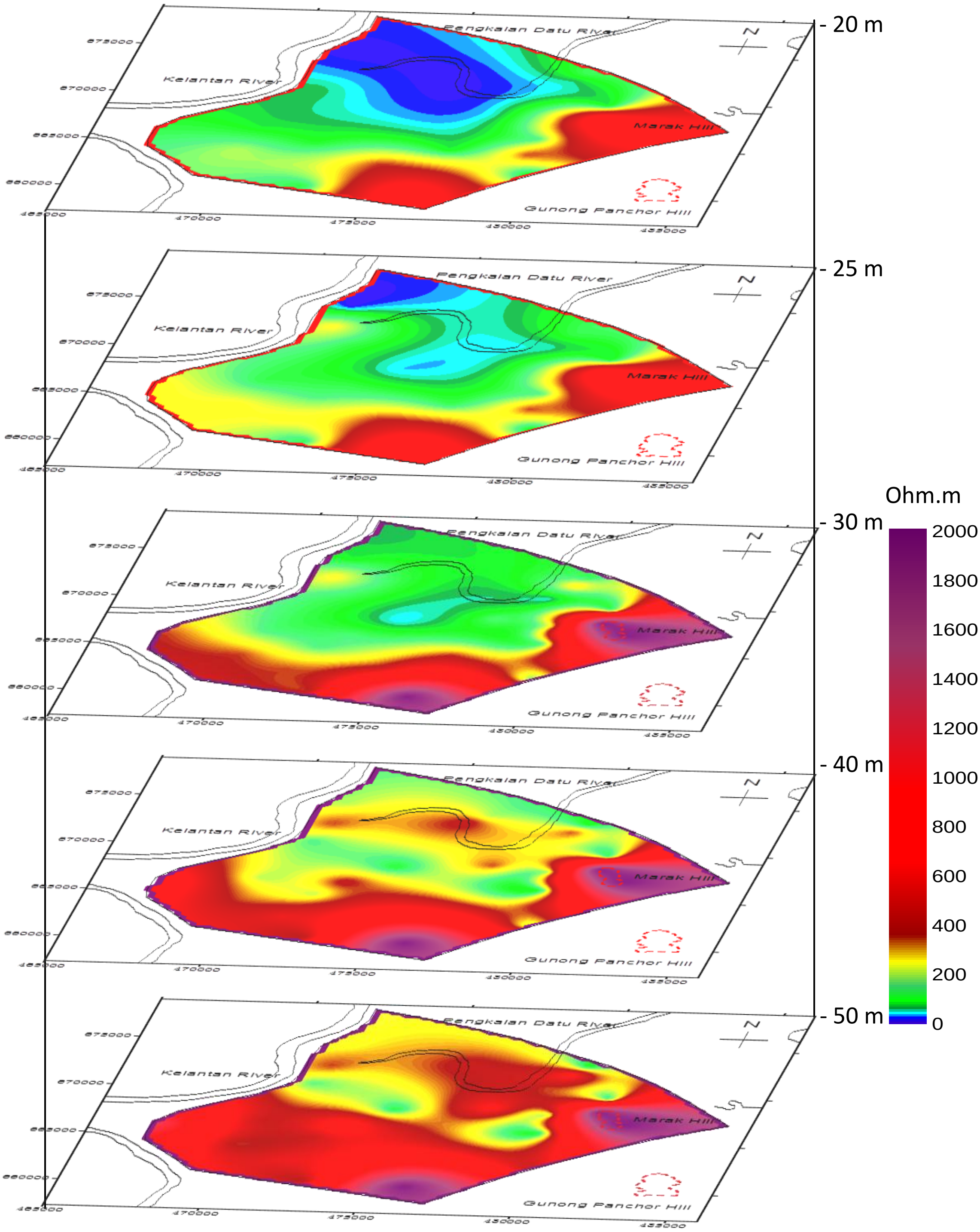


Figure 5.34. Depth slice resistivity distribution. Higher resistivity value appear around Marak Hill, whilst relatively lower resistivity value make a trend from south to north (Continued).

5.3. Sources of Groundwater Pollution

As discussed in subchapter 5.2, relatively lower resistivity values of around 15 ohm.m (next referred as anomaly) were found in geoelectrical models of lines A201, A205, A206, A216, A217 and A223. The anomaly is almost similar to the alluvium formation saturated by the light brackish water (Chapter 6). In fact, it is almost impossible for the brackish water to be in the aquifer located as far as 15-18 km away from the nearest beach line. Furthermore, other survey lines located closer to the beach line including A203 and A204 do not show the same anomaly as found in geoelectrical model of lines A201, A205, A206, A216, A217 and A223. In addition, groundwater sample analysed from this area show no salt/brackish water indication (Table 5.1).

In this investigation, the cause of low resistivity anomaly will be discussed. A new well (WA2) was drilled in order to obtain soil sample and water sample. The well that was drilled in Area 1 (WA1) is also used in the interpretation for comparison. Other shallow soil samples were also obtained at several sites together with the water sample. The location map of both new wells and soil sample is given in Figure 5.35.

The well WA2 was drilled in Kampung Kadok adjacent to the line A223. Unfortunately, the boring equipment cannot be placed exactly at the interested zone (central of the anomaly) due to the equipment size which can block the public road. Regarding this problem, the place around 200 m after the ending of line A223 was chosen for boring location. For other lines where lower resistivity anomaly are found (A201, A205, A206, A216 and A217), the field conditions do not allow to bring the boring equipment to these site. The well WA2 has a diameter of 4 inch and a depth of 34.1 m. At this depth the drill bit has encountered the basement. Gravel was found at 60 cm before the drilling stopped. It was bunged after reaching a very compact material and the bit cannot move down.

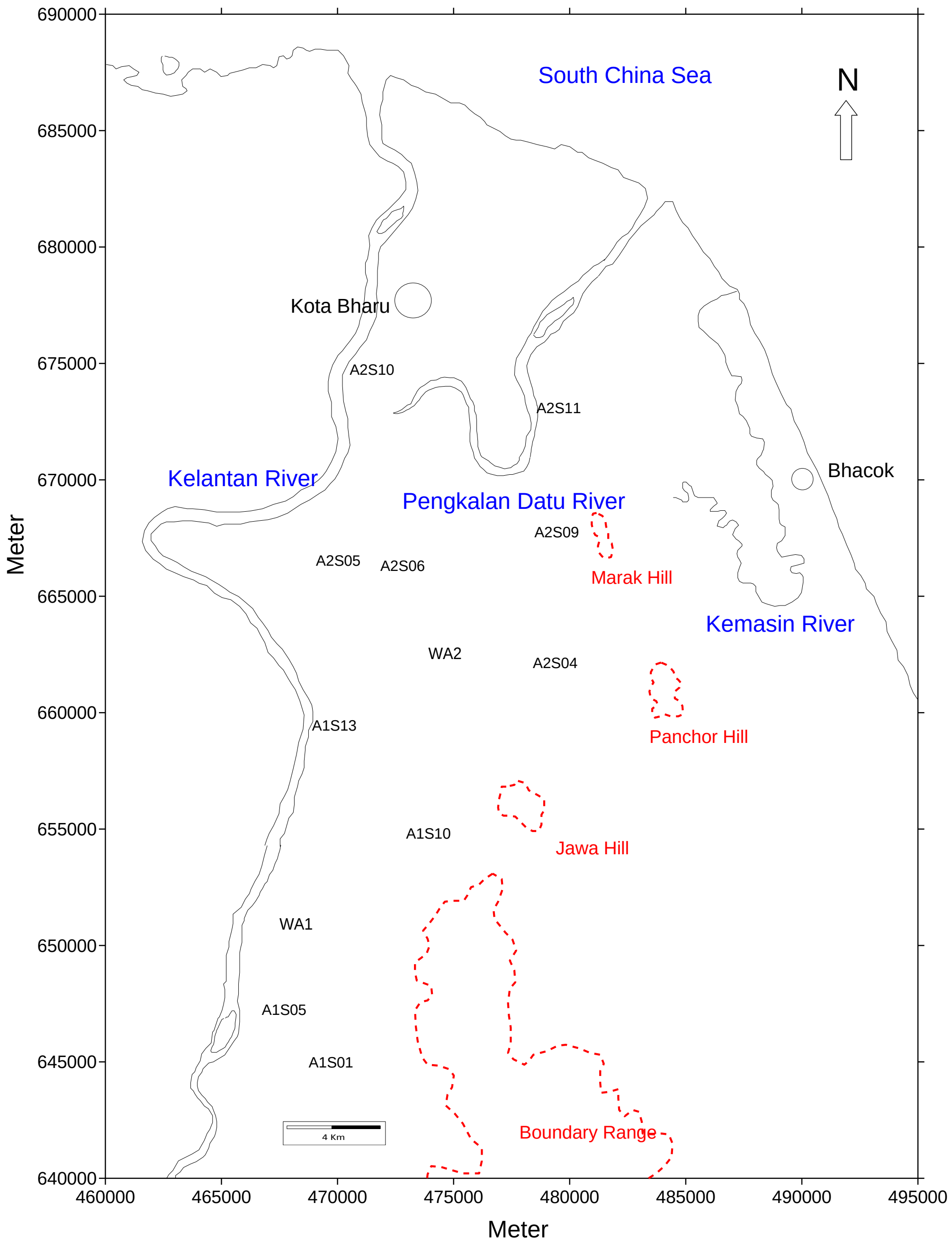


Figure 5.35. Locations of soil sample for chemical analysis.

The well WA1 was drilled in Area 1 that has relatively lower Fe concentration (less than 0.3 mg/L) in groundwater. It was installed at Kampung Pulai Condong 14 km away to the southwestern from WA2.

During the boring processes for both wells, soil that moved up for certain depth was collected for around 500 gr. The soil samples then kept at around 4^0C in plastic back until it was analysed in the hydrology laboratory. The water sample obtained from WA1 and WA2 were collected one day after the drilling completion.

Other soil samples were also obtained from several sites where the shallow aquifer water samples were collected. The soil samples were taken from 2 m depth using hand auger. The same collecting soil sample procedure from the two new wells was also used.

5.3.1. Soil Chemical Result

The result of soil chemical analysis of WA2 at various depths and other soil sample are given in Table 5.2. For comparison, the result of soil chemical analysis of WA1 is also shown in the same table.

For all soil cation content, Al has the highest concentration ranging from 47846.9 – 89251.6 mg/Kg in the WA2 and 37326.5 – 60414.2 mg/Kg in WA1, respectively. The second highest concentration is Fe ranging from 19157 – 52405.6 mg/Kg and 10510 – 17403.1 mg/Kg in the WA2 and WA1, respectively. Meanwhile Cu, Zn, As, Pb, Cd and Se concentration are less than 1000 mg/L. Figure 5.36 shows the concentration of Al and Fe in WA2 and WA1 for each depth sampling. Higher Fe concentration is obtained in between 15 and 30 m depth in WA2, whilst in WA1 the Fe concentration is found relatively lower than in WA2.

Table 5.2. Soil chemical results for W1, W2 at certain depth and several soils sampling at 2 m depth.

Sampling ID	Sampling Depth (m)	K mg/Kg	Ca mg/Kg	Mg mg/Kg	Pb mg/Kg	Cd mg/Kg	Se mg/Kg	Al mg/Kg	Mn mg/Kg	Cu mg/Kg	Zn mg/Kg	Fe mg/Kg	As mg/Kg	Na mg/Kg
WA2-02	2	11977.6	247.9	901.9	64.9	0.0	0.0	54634.4	118.7	44.5	50.5	19157.0	33.0	2778.7
WA2-05	5	19067.0	2533.9	2133.2	48.8	0.0	0.0	47846.9	553.2	45.3	39.9	27093.3	25.9	5338.9
WA2-08	8	15810.0	459.2	1940.2	71.6	0.0	0.0	64100.0	165.2	48.2	70.6	23020.0	28.2	2862.0
WA2-11	11	12559.7	778.5	2289.0	56.5	0.0	0.0	89251.6	242.8	39.2	49.2	29040.6	29.1	2571.7
WA2-14	14	11414.6	408.6	1125.9	55.5	0.0	0.0	53172.4	149.0	42.7	47.9	23483.6	31.9	2527.9
WA2-17	17	11547.8	369.3	460.8	75.3	0.0	0.0	58984.1	3195.2	40.6	54.2	44382.5	11.6	1139.6
WA2-20	20	16437.4	474.6	1291.7	65.8	0.0	0.0	83220.7	123.5	45.3	43.9	52405.6	31.4	2021.9
WA2-23	23	15326.3	106.4	974.3	65.1	0.0	0.0	60888.0	112.7	41.7	46.5	43378.4	36.7	1791.9
WA2-26	26	16921.2	301.9	1767.9	74.8	0.0	0.0	64777.2	213.4	51.9	81.7	42740.7	29.6	2136.0
WA2-29	29	18202.9	1003.2	3534.3	74.1	0.0	0.0	84904.2	324.5	74.9	73.7	24780.4	36.7	2122.6
WA2-32	32	15789.6	244.2	1523.3	69.6	0.0	0.0	60918.9	201.5	51.5	76.2	23309.5	31.2	2000.8
WA2-34	34	20100.0	836.4	3258.0	65.6	0.0	0.0	81620.0	354.6	63.0	74.0	24860.0	32.2	2288.0
WA1-02	2	20210.2	1251.1	2631.9	72.2	0.0	0.0	37326.5	298.7	41.1	89.6	10811.2	34.3	
WA1-05	5	20514.4	1406.3	2713.3	59.8	0.0	0.0	40550.2	266.1	39.1	61.8	12701.4	36.5	5077.8
WA1-08	8	12482.0	862.3	2526.0	65.9	0.0	0.0	58053.6	209.6	43.4	52.8	12554.0	56.4	2575.9
WA1-11	11	13821.2	908.4	936.3	67.5	0.0	0.0	60414.2	285.9	40.8	60.3	10810.4	31.3	3701.7
WA1-14	14	20298.8	584.9	1154.8	42.2	0.0	0.0	57928.3	162.0	20.1	29.3	10510.0	25.3	3468.1
WA1-17	17	21311.8	857.9	2234.8	68.6	0.0	0.0	53907.5	261.4	36.7	60.8	15412.7	36.3	5093.7
WA1-20	20	17176.8	813.0	2128.9	64.6	0.0	0.0	45171.6	212.7	35.7	59.5	13822.8	35.9	4068.2
WA1-24	24	20775.1	604.5	1155.8	68.7	0.0	0.0	60367.6	230.9	34.6	55.3	17403.1	37.4	4832.2
A1S01	2	332.2	212.9	104.3	79.1	0.0	0.0	35657.2	19.4	13.6	7.2	5727.1	37.2	428.1
A1S05	2	411.1	113.1	116.3	79.5	0.0	0.0	30843.0	11.4	11.0	6.8	2199.4	34.0	416.7
A1S10	2	808.6	193.0	661.6	132.0	0.0	0.0	51558.1	21.0	30.8	20.8	12331.2	56.1	1582.7
A1S13	2	6634.0	825.4	2193.4	102.1	0.0	0.0	75569.3	319.6	32.4	50.3	18597.7	42.3	2527.0
A2S04	2	14027.2	586.3	2059.5	114.1	0.0	0.0	70135.8	170.2	24.0	47.1	14224.9	50.1	2027.6
A2S05	2	8417.9	876.1	2341.2	102.1	0.0	0.0	100099.9	327.0	31.8	52.9	24910.1	47.7	2457.1
A2S06	2	7632.8	995.0	2233.3	101.3	0.0	0.0	95545.3	318.8	30.8	52.7	24570.5	48.3	2423.1
A2S09	2	19730.3	4312.8	2241.3	31.4	0.0	0.0	52357.2	239.9	28.4	26.6	16412.3	3.2	2568.9
A2S10	2	12111.5	627.2	2377.1	97.5	0.0	0.0	94406.7	280.7	32.0	50.7	15363.6	47.7	1867.4
A2S11	2	12928.5	513.2	2385.1	99.3	0.0	0.0	92469.0	161.0	25.6	46.1	16262.5	47.9	2219.3

In the soil sample for other locations, the lowest Fe concentration was found in A1S05 (2199.4 mg/Kg), and the highest Fe concentration is observed in A2S06 (24570.5 mg/Kg). Lowest (30843.0mg/Kg) and highest (100099.9 mg/Kg) Al concentration is also observed in the A1S05 and A2S05.

According to Taylor (1985), aluminium (Al) and iron (Fe) content in soil is dependent on the rock from which the soil parent material was derived and on the processes of weathering. Al and Fe are the most abundant metallic elements (e.g. Al2O3, 15.9%; FeO, 9.1%; MnO, 0.1%) in the continental crust.

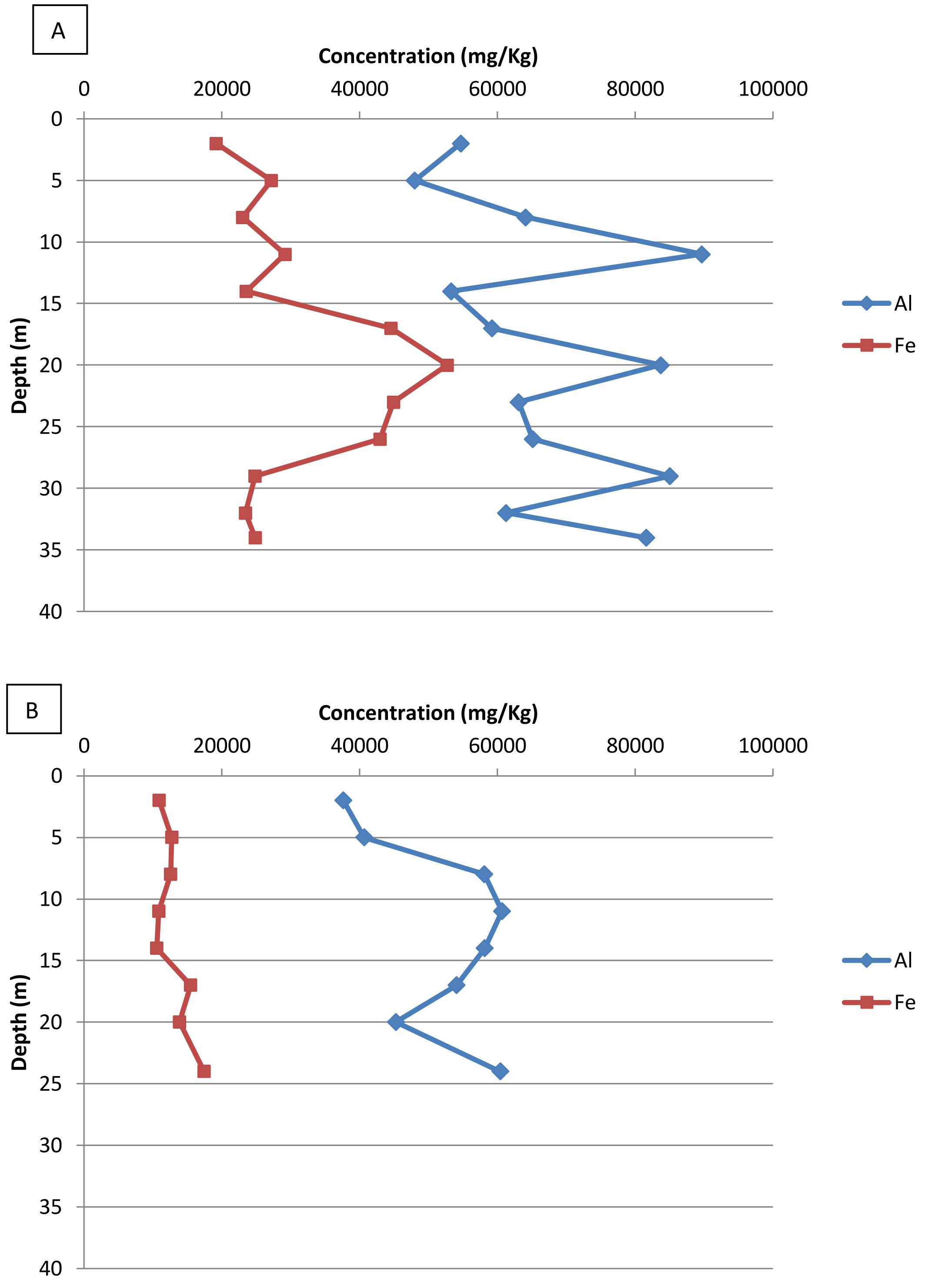


Figure 5.36. Al and Fe concentration in borehole WA2 soil sample (A) and WA1 (B). Relatively higher Al and Fe concentration found in WA2 compared to WA1.

5.3.2. Iron and Aluminium in Soil

Iron in groundwater can exist in two states; ferrous and ferric. The most common form of iron in solution in groundwater is the ferrous iron, Fe^{2+}. Ferric iron can exist in groundwater but at pH less than 4.8. Above this pH value the solubility of ferric species is less than 0.01 mg/L (Taylor, 1985).

The presence of high iron in the groundwater is clearly evident during collecting water from the Perol pumping wells station (KB21 and KB21). The water is clear (no colour) when it was collected directly from the pumping wells station. However, when the water is left standing for about an hour in a plastic bottle, it changes to reddish brown colour with precipitation of ferric iron. This is because when the groundwater is in contact with the air, the divalent ferrous iron which is soluble in water is oxidised by the oxygen from the air into its trivalent state to form ferric hydroxide. The trivalent iron is insoluble in water with natural pH and therefore precipitates out of the solution.

Iron occurs throughout the Kelantan area, in rocks and also as extensive lateritic deposits in low laying areas. The concentration of iron in groundwater is different for in each location (Ismail, 1992). There are also some occurrences of iron in the alluvium, but most of the mineral does not concentrate to such an extent as to constitute ore deposits. The main source of iron is primary one, siderite, which occurs at depths. Near the surface the deposit is residual of secondary origin (Noor, 1979).

The correlation between Al and Fe in soil samples is given in Figure 5.37. Low Fe concentration apparently is followed by low Al concentration. Based on the graph in Figure 5.37, it can be deduced that Fe and Al had the same source when they were deposited along geologic time.

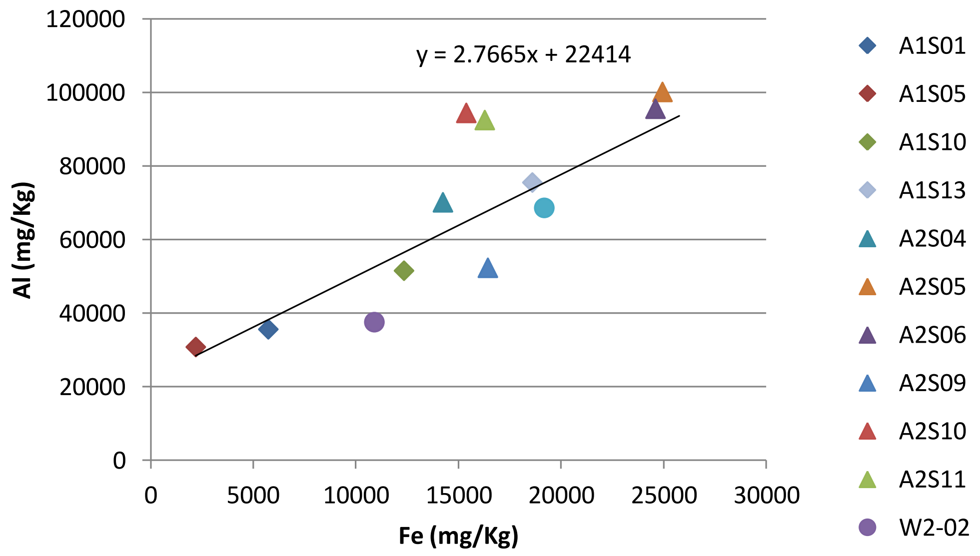


Figure 5.37. Correlation between aluminium and iron in soil sample.

Figure 5.38.A shows the correlation between Fe and Al in soil samples with Fe and Al in groundwater obtained from the well around where the soil samples were taken. Fe concentration in the groundwater is good correlated with Fe concentration in the soil (linier trend). This implies that Fe in groundwater is influenced by Fe concentration in soil. Higher Fe in soil will increase Fe in groundwater, whilst Al in ground water does not show any correlation with Al in soil. Al has a different character than Fe as it is not soluble in water under normal circumstances. Al forms during mineral weathering of feldspars, such as and orthoclase, anorthite, albite, micas and bauxite, and subsequently ends up in clay minerals. This is the reason Al also can be found in groundwater. However, because Al is not soluble in water, Al was found in groundwater less than 0.3 mg/L at the area which has higher Al concentration in the soil.

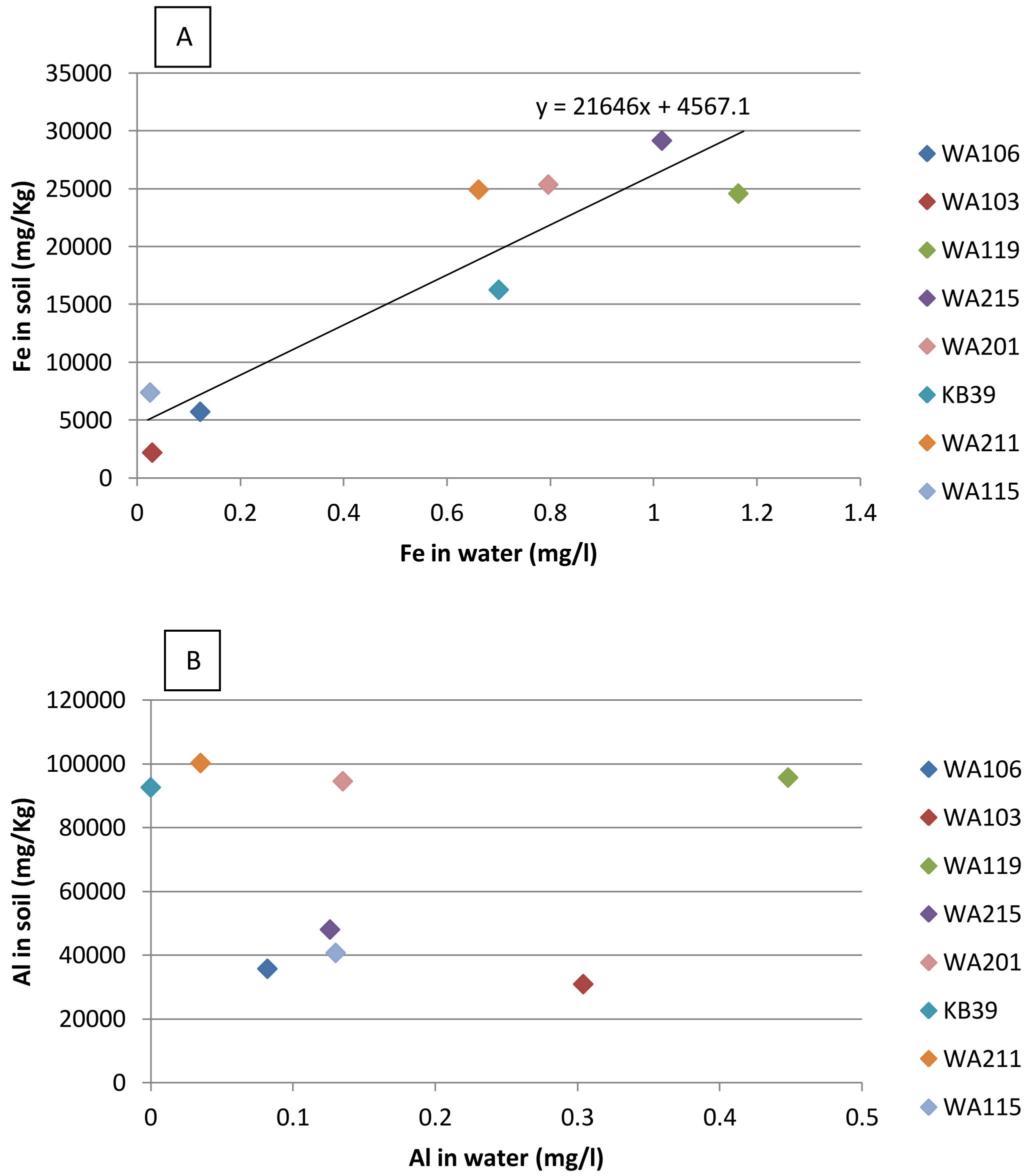


Figure 5.38. Correlation between Fe in soil and Fe in groundwater (A), and Al in soil and Al in groundwater (B)

In the Perol pumping well station (KB21 and KB21), which is around 3.5 km away from the WA2 well to northwest, dissolved Fe concentration in the groundwater has been found with an average 14 mg/L in 1990. The values fluctuated at around 13 mg/L in 1991 to 2007 (detailed data can be seen in Ismail (1995) and in the annual report of Mineral and Geosciences Malaysia). The last data derived in this study show its concentration around 12.5 mg/L (Table 5.1). Generally, Fe concentration in the Perol pumping well station decreases with time. The decreasing of Fe concentration in groundwater may correlate to the pumping intensity. The high rate of pumping water in the area causes water in the aquifer to be moved up and replaced by water from surrounding areas which has high hydraulic pressure than this area.

5.3.3. Iron Distribution in Aquifer

Figure 5.39, 5.40 and 5.41 shows the Fe concentration in a shallow aquifer at a depth of less than 10 m, 10-20 m and more than 20 m, respectively. In the Figure 5.39, 5.40 and 5.41, the colour and size of circle correlates to the amount of Fe concentration (see the map legend).

In Figure 5.39, the symbols coloured green and light blue indicate that the water is safe for human consumption. While the symbol coloured blue to brown indicate it is not safe for human consumption. Lower Fe concentration (green and light blue) is observed dominantly in the southern part of the study area, where 85% groundwater sample is safe for human consumption. Higher Fe concentration (blue to brown) dominates the northern area of Boundary Range and extents to the north. However in some location from Boundary Range to the north, lower Fe concentration is still can be found. The Fe concentration, however, decreases from the Boundary Range towards the sea.

In the aquifer with depth range from 10–20 m (Figure 5.40), there is no water sample taken from the southern part. The water sample is only available in the northern part. Fe concentration is less than 3 mg/L, except KB43, where Fe concentration is 11 mg/L. When compared to the water sample from shallow aquifer in Figure 5.39, Fe concentration in this depth interval is higher than in shallow aquifer.

In the aquifer with depth more than 20 m (Figure 5.41), only WA1 has Fe concentration less than 0.1 mg/L. All the water samples in this depth interval is more than 7 mg/l to 14 mg/l.

Based on the Fe concentration in groundwater plotted in Figure 5.39, 5.40 and 5.41, Fe concentration is seemly having the specific trend. Almost absent from the southern part at the shallow aquifer, and suddenly appear with higher concentration from the northern part of Boundary Range. From here, distribution of higher Fe concentration makes a slope seaward.

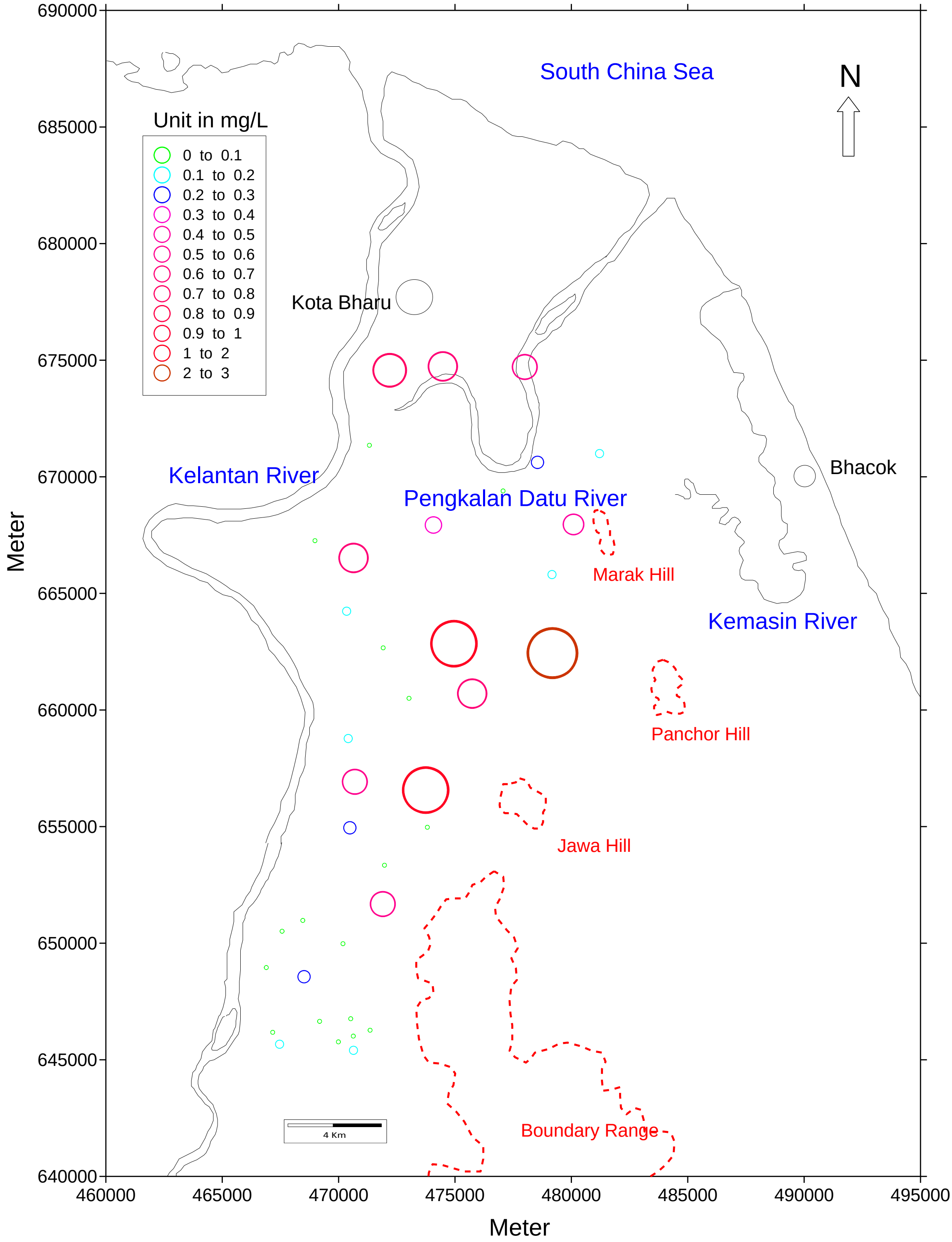


Figure 5.39. Fe concentration (mg/L) in shallow aquifer (less than 10 m depth).

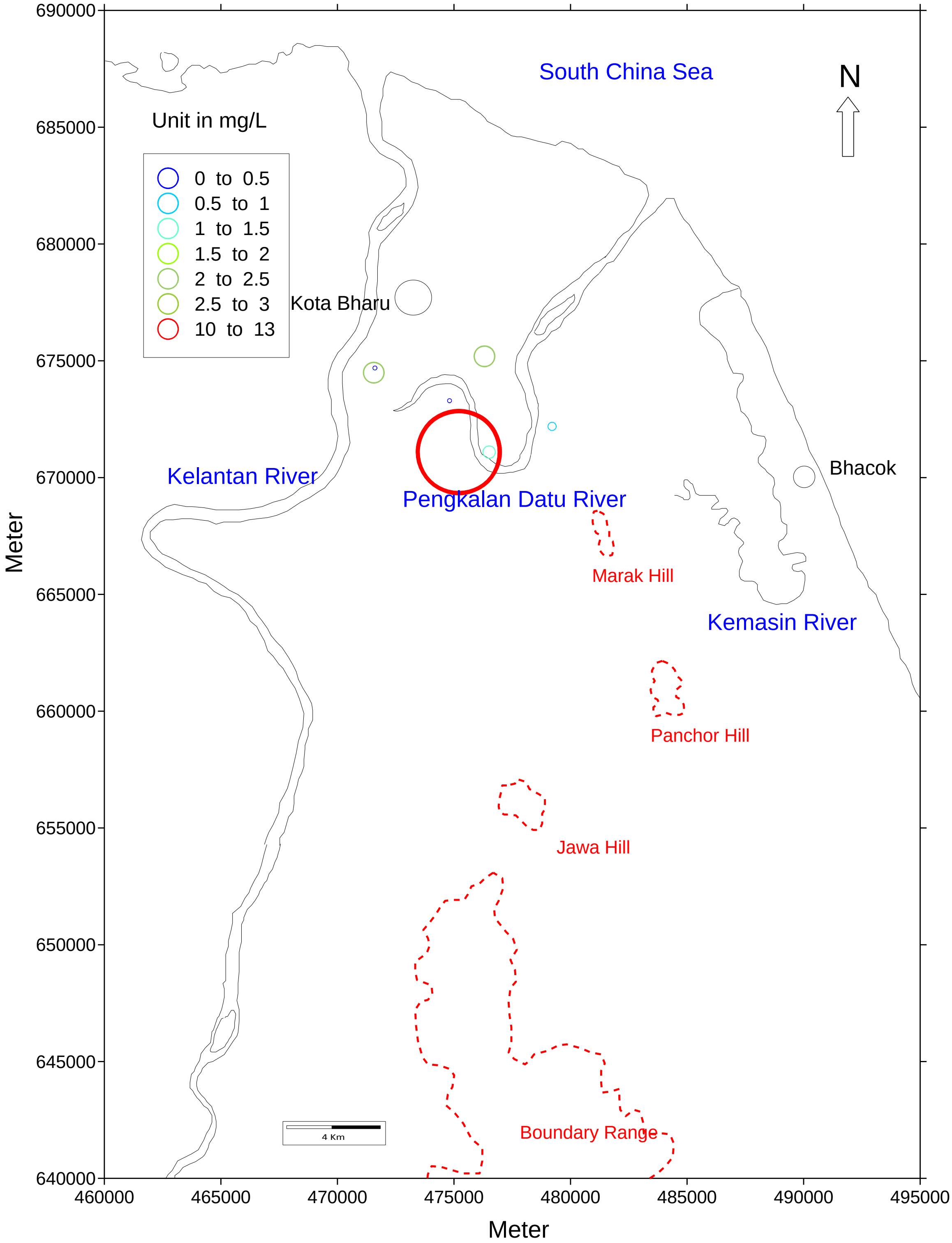


Figure 5.40. Fe concentration (mg/L) in aquifer with depth ranging from 10 m to 20 m.

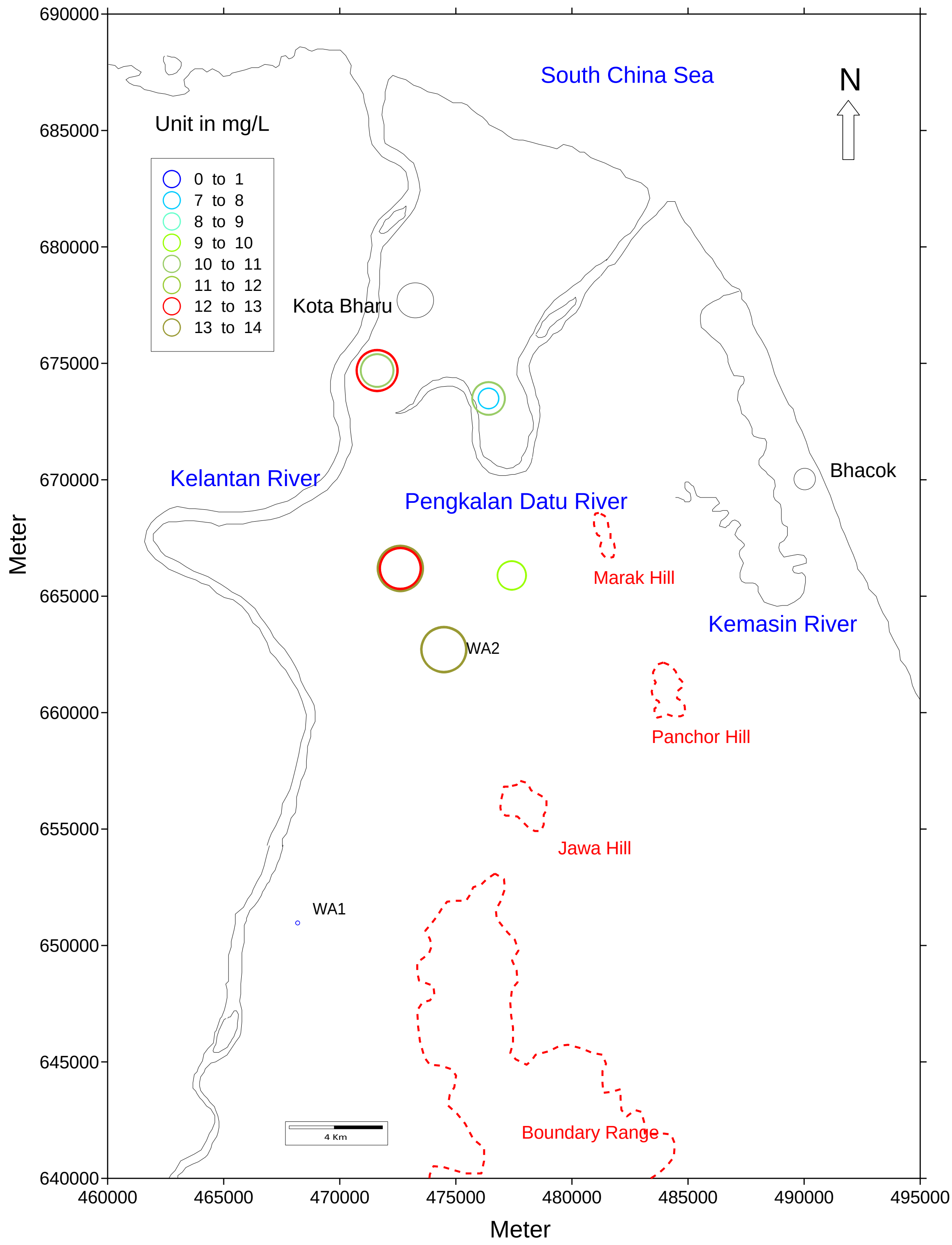


Figure 5.41. Fe concentration (mg/L) in aquifer with depth more than 20 m.

In all of the geoelectrical models discussed previously, the lower resistivity anomaly is observed in the area where the higher Fe and Al concentration was found. In well WA2, Fe and Al were found relatively higher in at depth below 15 m. The geoelectrical model shows relatively lower resistivity value at this depth interval. In the area which has lower Fe concentration, the geoelectrical model does not show any lower resistivity anomaly. Songyu et al. (2008), reported his experiment result that polluted soil by Fe has a good negative correlation with resistivity value.

Iron occurs throughout the Kelantan area, in rock and also as extensive lateritic deposits in low lying areas. The main source of iron is primary one, siderite, which occurs at depths, near the surface the deposit is residual of secondary origin (Noor, 1979). In this area, the source of lower anomaly (due to high heavy metal in aquifer system) is probably from the edge of the Boundary Range. The trend of lower resistivity anomaly is also supported by the trend of Fe concentration in groundwater. In the depth slice plot of resistivity distribution as given in Figure 5.34, the lower resistivity anomaly coloured blue is dominant in the southeast-northwest direction. Finally, the lower resistivity value in Figure 5.34 indicates higher Fe and Al concentrations in the quaternary sediment.

5.4. Summary

In Area 2, there is no indication of human activities that cause groundwater pollution. Agricultural activities including paddy planting and rubber tree plantation are not giving any impact in quality of groundwater. However, the groundwater has been polluted by natural process. Based on result of water chemical analysis, Fe concentration was found in all groundwater samples from various locations and depths. Fe concentration was found relatively lower and safe for human consumption in shallow aquifer at the southern and northwestern part. In the middle and northern part, Fe concentration tends to be higher and the water is not safe for human consumption.

Based on geoelectrical resistivity interpretation, zones of direct contact between surface water and shallow aquifer have been found at some places. At these zones, surface water has direct access into shallow aquifer. Providentially, human activities in this area do not give any contribution for water pollution especially in term of agriculture activities. In area around Pengkalan Datu River, geoelectrical resistivity model show clear connection between shallow aquifer and deeper aquifer directly. This is an evident that the possibility of the shallow and deeper aquifer are connected each others. Pre-Quaternary bedrock always appeared in almost all geoelectrical models. The depth of granite bedrock is varied in several places. It occurs as outcrop at around Marak Hill and deeper to the west ward. Generally, granite basement dips to the northwest.

At site with lower resistivity value, results of soil chemical analysis show that Fe and Al concentration is relatively higher. Fe concentration in soil show positive correlation with Fe concentration in groundwater around soil sampling area. High Fe concentration in soil causes high Fe concentration in groundwater. However there is no correlation between Al concentration in soil and in groundwater.

The zones of higher Fe concentration in aquifer system has been mapped along depth slice resistivity distribution. Fe concentration extends from the northern side of Boundary Range to the northwestern part. High Fe concentration occurs from depth of 0 to - 20 m above mean sea level in the southeast and lower towards the northwest. In the northwestern area, high Fe concentration occurs at depth of -5 to -25 m below the mean sea level. Within this depth interval, geoelectrical model shows lower resistivity anomaly (less than 15 ohm.m) in the zone with high Fe concentration within the aquifer system which also indicate high Fe concentration in groundwater (more than 7 mg/L). Finally, Fe concentration in aquifer system can be delineated through the depth slice resistivity distribution.