ABSTRACT

Integrated geoelectrical resistivity, hydrogeochemical and soil property analysis methods were used to study the groundwater characteristics and their associated problem in North Kelantan, Malaysia. A total area of 487 km^2 in this study is divided into three areas named Area 1, Area 2, and Area 3. The division is based on the geological and the environmental condition existing in the area.

A pilot investigation was done prior to the main investigation in the Area 1. From the surface to depths of 75 cm, a lower average resistivity was obtained in former regularly-fertilized site (around 0.37 times less than in non-fertilized site). The presence of nitrate and chloride contents in pore water reduced the resistivity values despite the low moisture content. In the southern region of Area 1, concentration of nitrate is considered to be high (>20 mg/l). In particular, at one of the catchment zone within palm oil plantation, nitrate concentration is found 140 mg/l. The geoelectrical model shows lower resistivity values (around 18 ohm.m) at the sites with relatively high nitrate concentration in the groundwater (> 20 mg/l). Conversely, the sites with low nitrate concentration exhibit the resistivity values to be higher (>35 ohm.m). One of the fundamental results here is that the nitrate content in pore soil is good correlated to the resistivity measurements.

The thickness of the aquifer ranges from 5 to 15 m and 25 to 40 m in the southern and northern of Area 1, respectively. Basement and groundwater potential maps are generated from the interpolation of an interpreted resistivity model. The geometry of potential aquifer is easily delineated from depth slice resistivity distribution and developed geological model.

A novel investigation in evaluation and monitoring of chemical fertilizer using geoelectrical method has been examined in the site where the nitrate concentration tends to be higher (palm oil plantation and tobacco area). In the palm oil plantation which the soil condition is semi-pervious characters, the hydrogeochemical measurements indicate that the cations content are relatively similar for every time lapse measurement. However, relatively higher changes of anions content occur near surface to a depth of 1 meter. Of particular interest is the nitrate concentration above the limit for safe human consumption as it returns to the initial value about 100 days after fertilization. In tobacco area which soil condition is in border line of semi-pervious and pervious characters, a similar fertilizer monitoring show that the nitrate concentration higher than the nitrate concentration in the palm oil area. Although amount of urea introduced in the tobacco area is 0.6 less than in palm oil plantation, but the growth of nitrate bigger around 1.4 more than in palm oil plantation area.

The pH values for the whole area range from 4.11 (minimum in Area 1) to 8.2 (maximum in Area 3), indicating that the groundwater is slightly acidic to slightly basic. The pH distribution is recognized that it has increasing trend from the south to the seaward. All the cation content is safe for human consumption except Fe. In the Area 1, the shallow groundwater sample (< 11 m depth) has a lower Fe concentration (0-0.3 mg/l). Whilst in the Area 2, a relatively higher (0.3 – 3 mg/l) Fe concentration is found in groundwater at the same depth interval in Area 1.

In the deeper aquifer of Area 2 and Area 3, Fe concentration exceeds far above safe for human consumption (0.3 - 14 mg/l). A novel study on using geoelectrical resistivity method for heavy metal investigation in aquifer system is demonstrated here. Soil chemical analysis shows that in the zone of lower resistivity value (< 15 ohm.m), Fe and Al concentrations are relatively high (average of 40000 mg/kg and 68000 mg/kg,

respectively). Lower resistivity value in the middle to the northwestern region of Area 2 is confirmed due to the high Fe and Al in the soil. This also is supported by the almost total lack of anion content in groundwater, while higher resistivity value in aquifers (> 40 ohm.m) is found in the zone with relatively lower Fe concentration in the groundwater (0-03 mg/l). Fe concentration in the soil has a positive linear correlation with Fe concentration in the groundwater, while Al concentration in groundwater has no correlation with Al concentration in soil. The possibility of high heavy metal in the aquifer is easily delineated in depth slice resistivity distribution. It extends from the north of Boundary Range Composite Batholith to the northwest. In some sites, shallow aquifer has direct contact with the surface which the surface water can infiltrate to the aquifer directly. This can be observed clearly in the geoelectrical model. In the site around Pengkalan Datu River, there is an indication of the shallow aquifer connected to the deeper aquifer.

Improvement on geoelectrical resistivity interpretation and imaging of the groundwater potential in the coastal area has been performed. Percentage content of seawater in the pore soil, the source of the soil samples and the percentage of clay content in the soil samples influence significantly the resistivity reading. An increase in the percentage of seawater content decreases the resistivity value drastically. The salt/brackish water make a small slope in the shallow aquifer from the beach to the landward until reach at a depth of around 10 m below 2 km from the beach line. Small slope shape and decreasing percentage of seawater content in the shallow and deeper aquifer is clearly seen through the geoelectrical resistivity model. The resistivity value is decreased to the seaward and increased to the landward. The brackish-fresh water interface in the interval depth of around 20-35 m curve toward the direction of water flow in the area around Pengkalan Datu and Kelantan River. This indicates that there is a possibility of groundwater in the aquifer being influenced by the river water.

ABSTRAK

Kaedah bersepadu kerintangan geoelektrik, hidrokemia, dan analisa properti tanah telah digunakan untuk mengkaji ciri-ciri air tanah dan masalah yang berkaitan dengannya di Kelantan Utara, Malaysia. Jumlah keluasan kawasan kajian adalah 487 km^2 yang dibahagi kepada tiga kawasan yang bernama Kawasan 1, Kawasan 2, dan Kawasan 3. Pembahagian ini adalah berdasarkan keadaan geologi dan alam sekitar yang sedia ada di kawasan itu.

Penyiasatan rintis telah dilakukan sebelum penyiasatan utama dalam Kawasan 1. Dari permukaan ke kedalaman 75 cm, purata kerintangan yang lebih rendah telah diperolehi di bekas lokasi yang kerap di bagi baja kimia (sekitar 0.37 kurang daripada di lokasi yang tidak dibagi baja kimia). Kehadiran nitrat dan klorida dalam air liang mengurangkan nilai kerintangan walaupun kandungan kelembapan rendah. Di rantau selatan Kawasan 1, kepekatan nitrat dianggap tinggi (>20 mg/l). Khususnya, di salah satu zon tadahan dalam ladang kelapa sawit, kepekatan nitrat ditemui 140 mg/l. Model geoelektrik menunjukkan nilai kerintangan lebih rendah (sekitar 18 ohm.m) di kawasan dengan kepekatan nitrat tinggi dalam air tanah (>20 mg/l). Sebaliknya, di kawasan dengan kepekatan nitrat rendah, mempamerkan nilai-nilai kerintangan yang lebih tinggi (>35 ohm.m). Salah satu keputusan fundamental disini adalah bahwa kandungan nitrat di dalam liang tanah adalah berkorelasi baik dengan pengukuran kerintangan.

Ketebalan akuifer adalah masing-masing antara 5 hingga 15 m di selatan dan 25 hingga 40 m di utara Kawasan 1. Peta batuan dasar dan potensi airtanah dihasilkan daripada interpolasi tafsiran model kerintangan geoelektrik. Geometri potensi akuifer mudah di amati daripada keping potongan kedalam kerintangan dan daripada model geologi yang dibuat.

Penyiasatan terbaru dalam pemantauan baja kimia menggunakan kaedah geoelektrik telah diuji di lokasi dimana kepekatan nitrat cendrung lebih tinggi (ladang kelapa sawit dan kawasan tembakau). Dalam ladang kelapa sawit yang mana keadaan tanah adalah semi pripius, pengukuran hidrokimia menunjukkan bahawa kandungan kation yang agak serupa setiap kali pengukuran. Walau bagaimanapun, perubahan anion relative lebih tinggi berlaku pada berhampiran permukaan ke kedalaman 1 m. Yang menarik adalah kepekatan nitrat yang melebihi had selamat untuk kegunaan manusia, dan ianya kembali ke nilai awal kira-kira 100 hari selepas pembajaan. Pada kawasan tembakau yang mana kondisi tanah disempadan semi-pripius dan pripius, prosedur pemantauan baja yang sama menunjukkan kepekatan nitrat lebih tinggi daripada kepekatan nitrat dalam kawasan kelapa sawit. Walaupun jumlah urea yang dibajakan dikawasan tembakau ialah 0.6 kurang daripada dalam ladang kelapa sawit, tetapi pertumbuhan nitrat lebih besar 1.4 kali berbanding dengan kawasan kelapa sawit.

Julat nilai-nilai pH bagi seluruh kawasan adalah dari 4.11 (minimum dalam Kawasan 1) kepada 8.2 (maksimum di Kawasan 3), menunjukkan bahawa air tanah adalah sedikit berasid dan sedikit asas. Taburan pH meningkat dari selatan menuju ke arah laut. Semua kandungan kation adalah selamat untuk kegunaan manusia kecuali Fe. Dalam Kawasan 1, sampel air tanah yang cetek (<11 m) mempunyai kepekatan Fe yang lebih rendah (0-0.3 mg/l). Namun di Kawasan 2, kepekatan Fe dijumpai dalam air tanah agak tinggi (0.3-3 mg/l) pada kedalaman interval yang sama dengan Kawasan 1.

Pada akuifer yang dalam di Kawasan 2 dan 3, kepekatan Fe melebihi jauh diatas selamat untuk kegunaan manusia (0.3 – 14 mg/l). Satu kajian terbaru menggunakan kaedah kerintangan geoelektrik untuk mengkaji logam berat dalam system akuifer ditunjukkan disini. Analisis kimia tanah menunjukkan bahawa dalam zon nilai kerintangan yang lebih rendah, (< 15 ohm.m), kepekatan Fe dan Al agak tinggi (purata 40000 mg/kg untuk Fe dan 68000 mg/kg untuk Al). Nilai kerintangan rendah di bagian

tengah ke bagian baratlaut disahkan akibat kehadiran Fe dan Al yang tinggi dalam tanah. Ini juga disokong oleh tiadanya kandungan anion dalam air tanah, sementara nilai kerintangan yang lebih tinggi (>40 ohm.m) di jumpai dalam zon dengan kepekatan Fe yang rendah (0-0.3 mg/l) dalam air tanah. Kepekatan Fe dalam tanah mempunyai korelasi linear positif dengan kepekatan Fe dalam air tanah, manakala kepekatan Al dalam air tanah tidak mempunyai kaitan langsung dengan kepekatan Al dalam tanah. Kebarangkalian kandungan logam berat yang tinggi dalam akuifer mudah ditandakan dengan keping potongan kedalaman taburan kerintangan geoelektrik. Ia bermula dari utara Boundary Range basolit ke barat laut. Pada lokasi-lokasi tertentu, akuifer cetek mempunyai hubungan langsung dengan permukaan, yang mana air permukaan boleh menyusup ke akuifer secara langsung. ini boleh dilihat dengan jelas pada model kerintangan geoelektrik. Dikawasan sekitar sungai Pengkalan datu, terdapat tanda-tanda bahwa akuifer cetek berkaitan langsung dengan akuifer yang lebih dalam.

Peningkatan pada cara tafsiran kerintangan geoelektrik dan pengimejan potensi air tanah dikawasan pesisir telah dilakukan. Peratus kandungan air laut dalam liang tanah, sumber sampel tanah diperoleh dan peratusan kandungan tanah liat didalam sampel tanah mempengaruhi bacaan kerintangan geoelektrik dengan ketara. Peningkatan dalam peratusan kandungan air laut menyebabkan berkurangan nilai kerintangan secara drastik. Air payau membuat sedikit cerun di akuifer cetek dari pantai kearah darat sehingga mencapai kedalaman kira-kira 10 m dibawah zon 2 km dari garis pantai. Bentuk cerun yang kecil dan pengurangan peratusan kandungan air laut didalam akuifer cetek dan dalam terlihat sangat jelas pada model kerintangan geoelektrik. Nilai kerintangan menurun kearah laut dan meningkat kearah darat. Antarmuka air payau dan air tawar dikedalaman sekitar 20-35 m melengkung kearah aliran air sungai dikawasan sekitar sungai Pengkalan Datu dan sungai Kelantan. Ini menunjukkan bahawa ada kemungkinan air tanah diakuifer dipengaruhi oleh air sungai.

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PREFACE

Alhamdulillah, finally this thesis entitled Integrated Geoelectrical Resistivity, Hydrogeochemical and Soil Property Analysis for Groundwater Investigation in North Kelantan, Malaysia, is completed.

This thesis was prepared as one of the requirement for the Ph.D Degree in Department of Geology, Faculties of Science, University of Malaya. The study was carried out from August 2008 to January 2010. The research focused on the groundwater investigation with its associated problem using integrated methods of geoelectrical resistivity, hydrogeochemical and soil property analysis.

This Ph.D. thesis contributes to the knowledge and literature via participation in different national and international conferences; and publication in a few journals. Selective publication includes:

ISI Journal

1. **Nur Islami**, Samsudin Hj Taib, Ismail Yusoff, Azman Abdul Ghani, 2012, Integrated Geoelectrical Resistivity, Hydrogeochemical and Soil Properties Analysis Methods to Study Shallow Groundwater in the Agriculture Area, Machang, Malaysia, Environmental Earth Sciences. Volume 65, Issue 3 (2012), Page 699-712, (DOI 10.1007/s12665-011-1117-6).
2. **Nur Islami**, Samsudin Hj Taib, Ismail Yusoff, 2011, Time-lapse Chemical Fertilizer Monitoring. International Journal Environmental Science Technology, Volume 8, No 4, 765-780
3. **Nur Islami**, Samsudin Hj Taib, Ismail Yusoff, 2012, Delineation of Heavy Metal Zone Using Geoelectrical Resistivity and Hydrogeochemical Methods. Submitted to Water Research

4. **Nur Islami**, Samsudin Hj Taib, Ismail Yusoff, 2012, High resolution of subsurface imaging in the coastal plain, North Kelantan, Malaysia. Submitted to Coastal Research

National and International Conferences

1. **Nur Islami**, Samsudin Hj Taib, Ismail Yusoff, 2011, Identification of heavy metal in groundwat, **The 4th AUN/SEED-Net Regional Conference on Geo-Disaster Mitigation** in ASEAN, 25-26 Oct 2011, Phuket, **THAILAND**.
2. **Nur Islami**, Samsudin Hj Taib, Ismail Yusoff, 2011, Groundwater mapping in coastal plain, North Kelantan, Malaysia, International Conference on Basic Science, 7-18 February 2011, Malang, **INDONESIA**
3. **Nur Islami**, Samsudin Hj Taib, Ismail Yusoff, 2010, High-resolution imaging of the groundwater mapping with geoelectrical resistivity tomography in coastal plain. North Kelantan – Malaysia, International Symposium on a Robust and Resilient Society against Natural Hazards & Environmental Disasters and the third AUN/Seed-Net Regional Conference on Geo-Disaster Mitigation August 24-26, 2010, Kyoto, **JAPAN**
4. Samsudin Hj Taib, **Nur Islami**, Ismail Yusoff, 2010, Time Lapse Monitoring of Chemical Content in Agricultural Sandy Soil, Machang – Malaysia. International Symposium on a Robust and Resilient Society against Natural Hazards & Environmental Disasters and the third AUN/Seed-Net Regional Conference on Geo-Disaster Mitigation August 24-26, 2010, Kyoto, **JAPAN**
5. **Nur Islami**, Samsudin Hj Taib, Ismail Yusoff, 2010, High-resolution imaging of the groundwater potentials with geoelectrical resistivity tomography in fluvial deposit, Machang. Kelantan – Malaysia, National Geosciences Conference 2010, 11-12 June 2010, Kuala Lumpur, **MALAYSIA**

6. **Nur Islami**, Samsudin Hj Taib, Ismail Yusoff, 2010, Geoelectrical ResistivityMethod –Some Application in Hydrogeological and Environmental Work, Seminar Dan Rapat Tahunan Bidang MIPA, 10-11 May 2010, Pekanbaru, **INDONESIA**
7. **Nur Islami**, Samsudin Hj Taib, Ismail Yusoff, 2010, Geoelectrical Resistivity and Hydrogeochemical Methods for Groundwater Investigation in the Agriculture Area: A Case Study from Machang – Malaysia, International Symposium and The 2nd AUN/SEED-Net Regional Conference on Geo-Disaster Mitigation in ASEAN. February, 25– 26, 2010. Bali, **INDONESIA**
8. **Nur Islami**, Samsudin Hj Taib, Ismail Yusoff, 2009, The Subsurface Geoelectrical Profiling of Tawang and Pangkalan Chepa Area – North Kelantan, Presenter, Eleventh Regional Congress on Geology, Mineral and Energy Resources of Southeast Asia (GEOSEA2009), 8 – 10 June 2009, Kuala Lumpur, **MALAYSIA**
9. **Nur Islami**, Samsudin Hj Taib, Ismail Yusoff, Jun 2008, Geophysical and Hydrochemical Method for Groundwater Investigation in North Kelantan, Presenter, Seminar on Postgraduate Seminar – Geology Dept, University of Malaya, **MALAYSIA**

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