

**HYDROGEOCHEMICAL STUDY AND IRON REMOVAL OF
GROUNDWATER IN NORTH KELANTAN**

NUR HAYATI BINTI HUSSIN

**FACULTY OF SCIENCE
UNIVERSITY OF MALAYA
KUALA LUMPUR**

2011

**HYDROGEOCHEMICAL STUDY AND IRON REMOVAL OF
GROUNDWATER IN NORTH KELANTAN**

NUR HAYATI BINTI HUSSIN

**DISSERTATION SUBMITTED IN FULFILMENT OF THE
REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE**

**DEPARTMENT OF GEOLOGY
FACULTY OF SCIENCE
UNIVERSITY OF MALAYA
KUALA LUMPUR**

2011

UNIVERSITI MALAYA

ORIGINAL LITERARY WORK DECLARATION

Name of Candidate: (I.C/Passport No:)

Registration/Matric No:

Name of Degree:

Title of Project Paper/Research Report/Dissertation/Thesis ("this Work"):

Field of Study:

I do solemnly and sincerely declare that:

- (1) I am the sole author/writer of this Work;
- (2) This Work is original;
- (3) Any use of any work in which copyright exists was done by way of fair dealing and for permitted purposes and any excerpt or extract from, or reference to or reproduction of any copyright work has been disclosed expressly and sufficiently and the title of the Work and its authorship have been acknowledged in this Work;
- (4) I do not have any actual knowledge nor do I ought reasonably to know that the making of this work constitutes an infringement of any copyright work;
- (5) I hereby assign all and every rights in the copyright to this Work to the University of Malaya ("UM"), who henceforth shall be owner of the copyright in this Work and that any reproduction or use in any form or by any means whatsoever is prohibited without the written consent of UM having been first had and obtained;
- (6) I am fully aware that if in the course of making this Work I have infringed any copyright whether intentionally or otherwise, I may be subject to legal action or any other action as may be determined by UM.

Candidate's Signature

Date

Subscribed and solemnly declared before,

Witness's Signature

Date

Name:

Designation:

This study has been presented in several conferences as listed below:

1. Name : Regional Conference On Ionic Liquid 2009 (RCiL09)
Date : 24th – 25th November 2009
Place : Faculty of Science, University of Malaya, Kuala Lumpur
Title : Removal of Fe(III) Ion from Groundwater Using Ionic Liquid as a Solvent Medium

2. Name : 1st National Conference On Natural Resources (NCNR2010)
Date : 18th – 19th May 2010
Place : Grand Riverview Hotel, Kota Bharu, Kelantan
Title : Preliminary Study on the Application of Ionic Liquid as a Solvent Medium for Iron Removal in Groundwater

3. Name : 6th Symposium of the International Geological Correlation Programme Project 516 (IGCP516) Geological Anatomy of East and South Asia
Date : 9th – 14th November 2010
Place : Faculty of Science, University of Malaya, Kuala Lumpur
Title : Hydrogeochemical Study of North Kelantan Aquifer

4. Name : The 6th Mathematics and Physical Science Graduate Congress 2010 (MPSGC2010)
Date : 13th – 15th December 2010
Place : Faculty of Science, University of Malaya, Kuala Lumpur
Title :
 1. Selected Ion Analysis of North Kelantan Aquifer
 2. Study of the Effectiveness of Ionic Liquid as a Solvent Medium for Iron Removal in Groundwater

ABSTRACT

The hydrogeochemical study and iron removal of groundwater was carried out in North Kelantan Basin. This low-lying area is covered by alluvium deposits of Quaternary age. The thickness of the alluvium may reach up to 200 m to the coast. Patches of granite hills appear in the southeast part known as Bukit Marak and Bukit Kechik that belong to Boundary Range Granite. Granite and metamorphic rock are encountered as bedrocks. Kelantan River is the main drainage of the basin with 248 km long and covers an area of approximately 11900 km². Hydrology study determined the baseflow index (BFI) of the basin as 0.54. This value is influenced by diverse geological, morphological and climatological aspects of the basin. Interaction between surface water and groundwater was found in the lower part of the basin while surface runoff dominated the process in the upper part of the basin. The total precipitation received in the basin was 30.95×10^9 m³/year. Water loss via potential evapotranspiration was about 40% with 50% of runoff coefficient. Based on water balance study, recharge to the aquifer was estimated about 11% from the total precipitation received. The thick sequences of alluvium deposits form an aquifer system in North Kelantan. Three layers of aquifer were identified; Layers 1, 2 and 3 with depth interval of 20 m, 20 – 50 m and more than 50 m, respectively. These layers are separated by semi permeable clay layer. Layer 1 is known as a remarkable source of public water supply in the study area as groundwater has been exploited since 1935. Hydrochemical facies reveal that the NaHCO₃ and NaCl facies are prevalent in the aquifer system. The evolution of groundwater is chemically governed by the process of weathering, dissolution, ion exchange and precipitation. Geochemical modeling indicates that the ferromagnesian minerals of hematite and goethite precipitate while pyrite undergoes dissolution leading to an increase of iron in groundwater. The groundwater is naturally rich with iron and exceeds the WHO (2008) acceptable limit

for drinking water. Presently, conventional groundwater treatment is being used to treat the groundwater for public, agricultural and industrial purposes. Ionic liquid as a medium in liquid-liquid extraction with 1,10-phenanthroline as a chelating agent was studied as an alternative method for iron removal. Successful removal of iron was achieved with more than 95% removal from the initial concentration of groundwater samples. However, more detailed research is needed before the ionic liquid is able to replace the conventional groundwater treatment as it gives a very low recovery about 25% - 60% when reused. Furthermore, due to the ion exchange process the appearance of anion of ionic liquid also has been detected in groundwater samples.

ABSTRAK

Kajian hidrogeokimia dan pengeluaran besi dari air tanah telah dijalankan di Lembangan Utara Kelantan. Dataran lanar ini diluputi oleh enapan alluvium yang berusia Kuaterner. Ketebalan enapan alluvium dianggarkan boleh mencapai sehingga 200 m ke arah laut. Tompokan granit ditemui di bahagian timur laut kawasan kajian yang dikenali sebagai Bukit Marak and Bukit Kechik yang dikatakan berasal dari 'Boundary Range Granite'. Lembangan ini disaliri oleh Sungai Kelantan dengan 248 km panjang yang meliputi kawasan seluas 11900 km². Kajian hidrologi menunjukkan bahawa indeks aliran dasar (BFI) bagi lembangan ialah 0.54. Nilai ini telah dipengaruhi oleh factor geologi, morfologi dan cuaca di lembangan. Hubungan di antara air sungai – air bawah tanah hanya berlaku di bahagian bawah lembangan manakala air larian mendominasi proses di bahagian atas lembangan. Jumlah hujan yang diterima di lembangan ialah 30.95×10^9 m³/setahun. Kehilangan air melalui potensi evapotranspirasi ialah 40% dengan 50% pekali air larian. Nilai imbuhan air tanah berdasarkan kajian keseimbangan air ialah 11% dari jumlah hujan yang diterima. Jujukan tebal enapan alluvium ini membentuk sistem akuifer di Utara Kelantan. Tiga lapisan akuifer telah dikenalpasti; Lapisan 1, 2 dan 3 dengan kedalaman meghampiri 20 m, 20 m ke 50 m dan lebih 50 m. Lapisan ini telah dipisahkan oleh lapisan lempung separa telap. Lapisan 1 merupakan sumber utama bekalan air di kawasan kajian yang telah dieksploitasi semenjak tahun 1935. Fasies hidrokimia yang utama dalam akuifer sistem ialah NaHCO₃ dan NaCl. Evolusi air tanah secara kimia dipengaruhi oleh luluhawa, pelarutan, pertukaran ion dan penganapan. Model geokimia menunjukkan mineral ferromagnesia seperti hematite dan goethite terenap manakala pirit mengalami pelarutan yang meningkatkan kandungan lagi besi dalam air tanah. Kandungan besi yang wujud secara semulajadi sangat tinggi dalam air tanah dan melebihi piawaian air

minuman WHO (2008). Sehingga kini, kaedah perawatan air secara tradisional telah digunakan bagi merawat air tanah untuk kegunaan awam, pertanian dan industri. Cecair ionik 1-butyl-3 methylimidazoliumbis(trifluoromethanesulfonyl)imide [C₄mim][NTf₂] sebagai medium dalam pengekstrakan cecair-cecair dengan 1,10-phenanthroline sebagai agen pengkelatan. Besi telah berjaya dikeluarkan lebih 95% daripada jumlah kepekatan awal sampel air tanah. Walau bagaimanapun, kajian yang lebih terperinci perlu dilakukan sebelum cecair ionik ini boleh dikitar semula dan dapat menggantikan kaedah perawatan air secara tradisional di mana jumlah kebolehdapatan semula yang rendah antara 25% - 60% selepas dikitar semula. Tambahan pula, proses penukaran ion yang berlaku telah menyebabkan hadirnya anion cecair ionic dalam sampel air tanah.

ACKNOWLEDGEMENT

All praise to Allah s.w.t. for giving me an opportunities, guidance and strengthern to weather the vagaries of life. Also, peace and blessings be upon the Prophet Muhammad as a great last messenger.

My sincere and deeply gratitude to all my supervisors Assoc. Prof. Dr. Ismail Yusoff, Prof. Dr. Yatimah Alias and Dr. Sharifah Mohamad for their patience, guidance, support, motivation, constructive criticisms and invaluable knowledge given throughout the research study.

Gratitude continue to University of Malaya, UMCiL, Geohydrology Group, Air Kelantan Sdn. Bhd., Minerals and Geoscience Department (MGD), Department of Irrigation & Drainage (DID), Department of Agriculture (DOA) and Malaysia Meteorological Department (MMD) for the financial resources and providing the data needed in this research.

Special thank to Geology and Chemistry Department staff especially Mr. Mohd Yusri Abdul Rahim, Mr. Mohd Noor Aizad Murad, Mr. Nur Islami Rahman and Mr. Ahmad Farid Abu Bakar for assistance in fieldwork, laboratory analysis, computer software and others.

My clicks in Geology and Chemistry Department (Ms. Anis Suhaila, Ms. Nor Bakhiah, Ms. Nurul Yani, Mrs. Nurul Huda, Ms. Siti Nurur Raihan, Ms. Nor Liana, Ms. Nur Hafizah, Ms. Azmiah, Mrs. Nor Hidayah, Ms. Fairuz Liyana and other members of Hydrogeology, K012 and D220 laboratory) a million thanks to all for the support and sweet memory we having together, I really appreciate it.

Lastly, to others who their name are not mentioned above that involved directly or indirectly for making this thesis success.

*With Love,
~♥nhh 2011♥~*

DEDICATION

Dedicated to

My Beloved Dad and Mom

(Mr. Hussin Ahmad and Mrs. Ramlah Jopree)

also

My Beloved Siblings

(Ms. Nur Haniza, Mr. Mohd Hairi, Ms. Nur Azimah and Mr. Mohd Hafidz)

TABLE OF CONTENTS

CONTENTS	PAGE
ABSTRACT	ii
ABSTRAK	iv
ACKNOWLEDGEMENT	vi
DEDICATION	vii
TABLE OF CONTENTS	viii
LIST OF FIGURES	xiii
LIST OF TABLES	xvi
LIST OF APPENDICES	xviii
LIST OF ABBREVIATIONS AND SYMBOLS	xix
CHAPTER 1: INTRODUCTION	
1.1 INTRODUCTION	1
1.2 OBJECTIVES	4
1.3 STUDY AREA	4
1.4 GEOMORPHOLOGY	5
1.4.1 Topography	5
1.4.2 Climate	7
1.4.3 Drainage System	8
1.4.1 Land Use	9
1.5 LITERATURE REVIEW	10
1.5.1 Geology	10
1.5.2 Geomorphology	11
1.5.3 Hydrogeology	13
1.5.4 General Iron Removal from Groundwater	15
1.5.5 Ionic Liquid as Medium for Removal Metals Ion in Groundwater	17
1.6 GENERAL METHODOLOGY	17
1.6.1 Desk Study	17
1.6.2 Fieldwork	18

1.6.3	Laboratory	18
1.6.4	Data Analysis and Thesis Writing	19
1.7	THESIS OUTLINE	19

CHAPTER 2: GEOLOGY AND HYDROLOGY

2.1	INTRODUCTION	20
2.2	METHODOLOGY	20
2.2.1	Geology	20
2.2.2	Hydrology	20
	Precipitation	22
	Potential Evapotranspiration (PE)	23
	River Discharge	24
	Baseflow	24
	Water Balance	25
2.2.3	Hydrogeology	26
	Monitoring wells	26
2.2.4	Conceptual Model	34
2.3	RESULTS	34
2.3.1	General Geology of Kelantan	34
	Paleozoic	34
	Mesozoic	36
	Cenozoic	36
	Plutonism	36
	Metamorphism	37
	Fault	38
2.3.2	General Geology of the Study Area	38
	Quaternary Deposit	38
	Gula Formation	40
	Simpang Formation	41
	Granite	41
2.3.3	Hydrology	42
	Precipitation, P	42
	Potential Evapotranspiration, PE	42

River Discharge	45
Baseflow Index	46
Water Balance	49
2.3.4 Hydrogeology	50
Groundwater Level	54
2.4 DISCUSSION	57
2.4.1 Geology	57
2.4.2 Hydrology	57
2.4.3 Hydrogeology	59
2.4.4 Conceptual Model	59

CHAPTER 3: HYDROGEOCHEMISTRY

3.1 INTRODUCTION	61
3.1.1 Physical Parameters ('in-situ')	61
3.1.2 Chemical Parameters	63
3.2 METHODOLOGY	64
3.2.1 Software	65
3.2.2 Hydrochemical Facies	65
3.2.3 Saturation Index	66
3.2.4 Rock Source Deduction	66
3.3 RESULTS	67
3.3.1 Physical Parameters	67
Temperature, °C	67
pH	67
Total Dissolved Solids (TDS), mg/l	69
Electrical Conductivity (EC), $\mu\text{S}/\text{cm}$	71
3.3.2 Chemical Parameters (Cations)	73
Sodium, Na^+	73
Potassium, K^+	73
Calcium and Magnesium as Indicator for Water Hardness	75
Iron, Fe_{total}	78
Manganese, Mn^{2+}	82

Ammonium, NH ₄ ⁺	83
Other cations	85
3.3.3 Chemical Parameters (Anions)	85
Chloride, Cl ⁻	85
Sulfate, SO ₄ ²⁻	87
Nitrate, NO ₃ ⁻	87
3.4 DISCUSSION	89
3.4.1 Relationships Selected Parameters with Depth	89
Sodium and Chloride	89
Iron	90
Nitrate and Ammonium	91
3.4.2 Hydrochemical Facies	93
3.4.3 Groundwater Evolution	96
3.4.4 Saturation Index	102
3.4.5 General Groundwater Quality	105
Drinking Purposes	105
Irrigation Purposes	109

CHAPTER 4: GROUNDWATER TREATMENT METHOD FOR IRON REMOVAL

4.1 INTRODUCTION	113
4.1.1 Problem in Kelantan Groundwater	113
4.1.2 Groundwater Abstraction in Kelantan	115
4.1.3 Groundwater Treatment in Kelantan	117
4.1.4 General Description of Ionic Liquids	118
4.1.5 Ionic Liquids as a Medium in Liquid-Liquid Extraction	120
4.2 METHODOLOGY	122
4.2.1 Sampling Points	122
4.2.2 Chemicals and Solutions	124
4.2.3 Instrumentations	124
4.2.4 Extraction Procedures	125
4.2.5 Stripping Procedures	125

4.2.6	Reuse/Recycle Procedures	126
4.3	RESULTS AND DISCUSSION	127
4.3.1	Effect of pH	127
4.3.2	Effect of Solvents	128
4.3.3	Effect of Time Shaking	129
4.3.4	Effect of Phase Ratio	130
4.3.5	Effect of Stripping Agent	131
4.3.6	Regeneration of Ionic Liquid	132
4.3.7	Application of Ionic Liquid using Groundwater Samples	133
	Physical and Chemical Parameters	133
	Removal of Metal Ions	133
	Stripping of Ionic Liquid	135
	Analysis of Anion	136
	CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS	139
	REFERENCES	144

LIST OF FIGURES

Figure 1.1	Waterworks Location in North Kelantan	4
Figure 1.2	Location of the Study Area	5
Figure 1.3	Digital Terrain Model of Kelantan Showing Mean Elevations	6
Figure 1.4	Digital Ground Slope Model of Kelantan	6
Figure 1.5	Annual Rainfall (1979 – 2008). Average Annual Rainfall is 2543.87 mm	8
Figure 1.6	Map of Drainage System in North Kelantan	9
Figure 1.7	Main Land Use for Kota Bharu, Tumpat and Bachok Districts (2006)	10
Figure 1.8	Hydrogeological Map of Peninsular Malaysia	14
Figure 1.9	General Flow of Methodology in this Study	17
Figure 2.1	Precipitation Area Using Thiessen Polygon Method.	22
Figure 2.2	Baseflow Separation Method (Ineson and Downing, 1964)	25
Figure 2.3	Typical Design of Monitoring Well	27
Figure 2.4	JKR Monitoring Well Design	27
Figure 2.5	Well Locations in Layer 1	29
Figure 2.6	Well Locations in Layer 2	31
Figure 2.7	Well Locations in Layer 3	33
Figure 2.8	Geology Map of Kelantan	35
Figure 2.9	Geology Map of North Kelantan	39
Figure 2.10	Mean Monthly Precipitation Distribution (1979 – 2008) Recorded from 4 Stations	43
Figure 2.11	Percentage of Surface Types in Kelantan River Basin	44
Figure 2.12	Annual Distribution of Potential Evapotranspiration (PE) with Mean Annual of 1037.12 mm/year	45
Figure 2.13	Annual River Discharge at Guillemard Bridge (1979-2008) with Mean Values of 486.26 m ³ /s.	45
Figure 2.14	Discharge Hydrograph at Guillemard Bridge from 1979 – 2008	47
Figure 2.15	Hydrogeological Fence Diagram (Adapted from Mohammad & Ang, 1996)	51
Figure 2.16	Groundwater Level (a), (b) and (c) in North Kelantan River Basin	55

Figure 2.17	The Conceptual Model of Kelantan River Basin	60
Figure 3.1	pH Value in Layers 1, 2 and 3	67
Figure 3.2	Distribution of TDS and Conductivity in Layers 1, 2 and 3	70
Figure 3.3	Map of TDS in Layer 2. Red Contour Line Indicated the Interface between Fresh Water and Brackish Water. Inlet Map Show Interface between Fresh and Brackish Water using Geophysical Method by Samsudin <i>et al.</i> (2008)	72
Figure 3.4	Contour Pattern of a) Sodium; b) Potassium in Layers 1, 2 and 3	74
Figure 3.5	Contour Pattern of a) Calcium; b) Magnesium in Layers 1, 2 and 3	77
Figure 3.6	Pie Chart Percentage of Hardness in Layers 1, 2 and 3	79
Figure 3.7	Distribution of Iron _{total} in Layers 1, 2 and 3	79
Figure 3.8	Contour Pattern of a) Iron _{total} ; b) Manganese in Layers 1, 2 and 3	81
Figure 3.9	Distribution of Manganese in Layers 1, 2 and 3	82
Figure 3.10	Distribution of Ammonium in Layers 1, 2 and 3	83
Figure 3.11	Contour Pattern of Ammonium in Layers 1, 2 and 3	84
Figure 3.12	Contour Pattern of a) Chloride; b) Sulfate in Layers 1, 2 and 3	86
Figure 3.13	Contour Pattern of Nitrate in Layers 1, 2 and 3	88
Figure 3.14	Variation of Sodium and Chloride with Depth	89
Figure 3.15	Variation of Iron _{total} with depth	90
Figure 3.16	Variation of Nitrate with Depth	91
Figure 3.17	Variation of Ammonium with Depth	92
Figure 3.18	a) Piper Diagram; b) Spatial Distribution of Stiff Diagram in Layers 1, 2 and 3	94
Figure 3.19	Schematic Diagram of Groundwater Evolution in North Kelantan	101
Figure 3.20	Saturation Index in Layers 1, 2 and 3.	103
Figure 3.21	Ionic Ratios of a) Na/Cl vs Cl; b) Ca/Mg vs Cl; c) Ca/SO ₄ vs Cl in Layers 1, 2 and 3.	104
Figure 3.22	Wilcox diagram (a); (b); (c) in Layers 1, 2 and 3	110
Figure 4.1	Schematic Flow of Conventional Groundwater Treatment	117
Figure 4.2	Common Cation and Anion Used in Ionic Liquids (James and Davis, 2004 & Sharma, 2008)	119
Figure 4.3	a) Structure of [C ₄ mim][NTf ₂] and b) 1, 10-phenanthroline	122
Figure 4.4	Groundwater Sampling Point Locations	123

Figure 4.5	Schematic Flow of Iron Extraction and Stripping Process	126
Figure 4.6	Effect on pH on the Extraction (%) of Fe ³⁺ and Fe ²⁺ Ion	127
Figure 4.7	Phase Separation a) Ionic Liquid; b) Chlorobenzene; c) Chloroform	128
Figure 4.8	Effect on Types of Solvent on the Extraction of Fe ³⁺ and Fe ²⁺ Ions	129
Figure 4.9	Effect of Time Shaking on the Extraction of Fe ³⁺ and Fe ²⁺ Ion	129
Figure 4.10	Effect of Ratio Aqueous/Organic on the Extraction of Fe ³⁺ and Fe ²⁺ Ion	130
Figure 4.11	Effect of Stripping Agent on the Extraction of Fe ³⁺ Ion	131
Figure 4.12	Recovery (%) of Fe(III) Ion	132
Figure 4.13	Removal of Iron and Other Heavy Metals in Groundwater Samples	135
Figure 4.14	Recovery (%) of Iron	135
Figure 4.15	Aqueous Phase Sample KB31	137
Figure 4.16	Ionic Liquid Phase Sample KB31	138
Figure 5.1	Conceptual Model of North Kelantan	142

LIST OF TABLES

Table 1.1	List of Waterworks in Kelantan	3
Table 1.2	Topographic Units according to mean Elevations	7
Table 1.3	Slope and Terrain Classes, after Leamy and Panton (1960)	7
Table 1.4	Type of Data Used in This Study	18
Table 2.1	Sources and Methods Use for Hydrology Component.	21
Table 2.2	General Information of Monitoring Wells in Layer 1	28
Table 2.3	General Information of Monitoring Wells for in Layer 2	30
Table 2.4	General Information of Monitoring Wells in Layer 3	32
Table 2.5	Mean Monthly and Annual Precipitation	43
Table 2.6	Classification of Selected Surfaces in Kelantan River Basin	44
Table 2.7	Yearly Baseflow and Total Flow	48
Table 2.8	Baseflow Index (BFI) of North Kelantan River Basin	46
Table 2.9	Calculated Precipitation using the Thiessen Polygon Method	49
Table 2.10	Water Balance Data for North Kelantan River Basin	49
Table 2.11	Aquifer Properties (Transmissivity, Permeability and Storage) by MGD	53
Table 2.12	Aquifer Properties (Transmissivity, Permeability and Storage) by Binnie & Partners.	54
Table 2.13	Fluctuation of Groundwater Level in Layer 1	56
Table 2.14	Fluctuation of Groundwater Level in Layer 2	56
Table 2.15	Fluctuation of Groundwater Level in Layer 3	56
Table 3.1	Summary of Physical Parameters	62
Table 3.2	Major, Minor and Trace Constituents of Water.	63
Table 3.3	Summary of Chemical Parameters	64
Table 3.4	Saturation Index	66
Table 3.5	Physical and Chemical Parameters in Layer 1, 2 and 3.	68
Table 3.6	Simple Groundwater Classification Based on Total Dissolved Solids (TDS)	69
Table 3.7	Recommended Fertilizer Rates for Crops on Mineral Soils	75
Table 3.8	Hardness Classification of Water (Todd, 2005)	76

Table 3.9	Hardness Classification in Layers 1, 2 and 3. Value in bracket are in percentage (%)	78
Table 3.10	Hydrochemical facies of North Kelantan	95
Table 3.11	Ratio Source Rock Deduction in Layers 1, 2 and 3	97
Table 3.12	Mean Values of Saturation Index in Layers 1, 2 and 3	103
Table 3.13	Classification of Irrigation Water Based on SAR Values	109
Table 3.14	Suggested Criteria for Irrigation Water Use Based Upon Conductivity (Bauder et al, 2007)	111
Table 4.1	Statistics of <i>Haemochromatosis</i> Cases from 1996 – 2009	115
Table 4.2	Groundwater Abstraction in North Kelantan from 1974 – 1995 (GSD, 1995)	116
Table 4.3	Estimation Kelantan Groundwater Demand in 2010	116
Table 4.4	General Characteristic of the Selected Sampling Points	123
Table 4.5	Mean Values of Physical and Chemical Parameters of Groundwater Samples	134

LIST OF APPENDICES

- Appendix 1 Selected Rainfall Station Data
- Appendix 2 Selected Discharge Station Data
- Appendix 3 Example Borehole Log Data
- Appendix 4 Example of Aquachem Sample Summary Report

LIST OF ABBREVIATIONS AND SYMBOLS

%	-	percent
AKSB	-	Air Kelantan Sdn. Bhd.
APHA	-	American Public Health Association
CDC	-	Centers for Disease Control
DID	-	Department of Irrigation and Drainage
DOA	-	Department of Agriculture
EC	-	Electrical Conductivity
GHM	-	German Hydrological Mission
GSD	-	Geological Survey Department
ICP-OES	-	Inductively Coupled Plasma Optical Emission Spectrometer
ILs	-	Ionic liquids
INWQS	-	Interim National Water Quality Standard
mg/L	-	Milligram per liter
MGD	-	Mineral and Geosciences Department
MLD	-	Million liter per day
MMD	-	Malaysian Meteorology Department
MOH	-	Ministry of Health
RTILs	-	Room Temperature Ionic Liquids
SAR	-	Sodium Adsorption Ratio
TDS	-	Total Dissolved Solids
WHO	-	World Health Organization