

**STUDY OF HYDROCHEMISTRY AND  
SEAWATER INTRUSION OF MANUKAN  
ISLAND, SABAH**

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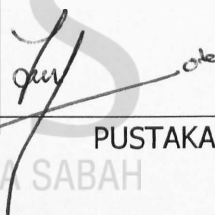
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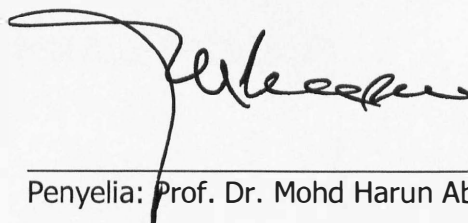
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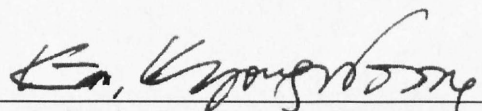


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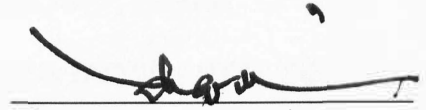
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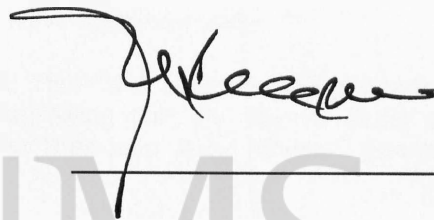
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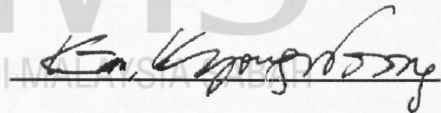
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## ABSTRACT

### STUDY OF HYDROCHEMISTRY AND SEAWATER INTRUSION OF MANUKAN ISLAND, SABAH

A detailed groundwater, seawater and sediment study were undertaken to examine the evolution of groundwater in the shallow aquifer of Manukan island, Sabah, Malaysia. Its aquifer is often exposed to heavy pumping and that could lead to seawater intrusion. The continuous pumping of groundwater on this island has contributed to enrichment of some constituents found in seawater. As a consequence of indiscriminate exploitation, the groundwater quality of this island has deteriorated. Major ion chemistry analysis shows that the groundwater quality of the island experiences some changes attributed to seawater intrusion. Simple mixing between seawater-freshwater is complicated by the cation exchange process and highly associated with groundwater withdrawal. This study indicates that the groundwater is classified as Na-Cl and Ca-Cl types. The groundwater has undergone a compositional change from Ca-rich to Na-rich which can be explained mostly by the cation exchange process. This study shows that the rise of Na and Cl composition in the groundwater is not only controlled by seawater intrusion, but also controlled by rapid cation exchange processes. Strong correlations exist among the major elements (Na, Mg, K, Cl and  $\text{SO}_4$ ) and salinity with/or EC suggest that the impact of seawater intrusion to these major elements are more significant due to highly competitive relationship between ions. These relationships clearly identify the main elements contributing to the groundwater salinity and their tendency to depict a similar trend of salinization pattern. From the PHREEQC calculation, calcite, dolomite and aragonite solubility showed positive values of the saturation indices (SI), indicating supersaturation that lead to mineral precipitation condition of water by these minerals. Intensive exploitation of groundwater from Manukan Island's aquifer has disturbed the natural equilibrium between fresh and saline water, and has resulted in the increase of groundwater salinity and leap to the hydrochemical complexities of freshwater-seawater contact. It was observed that the mixing between freshwater-seawater created diversity in the geochemical processes of Manukan Island's aquifer and altered the freshwater and seawater mixture away from the theoretical composition line. This explained the most visible processes taking place during the displacement. The results from reactive transport modelling confirmed that the migration of seawater into the fresher parts of the aquifer apparently leads to a calcification of the aquifer despite the seawater being supersaturated for carbonate minerals and shows that the composition of the near coast zone and further landward area may vary and have a significant effect on the processes during the intrusion.

**Keywords:** groundwater, hydrochemistry, PHREEQC, seawater intrusion, small island

## ABSTRAK

Satu kajian terperinci terhadap air bawah tanah, air laut dan sedimen telah dijalankan bagi mengenal pasti proses evolusi air bawah tanah yang berlaku di dalam akuifer cetek Pulau Manukan, Sabah, Malaysia. Akuifernya terdedah kepada proses pengepaman yang boleh membawa kepada penerobosan air laut. Proses pengepaman air bawah tanah yang berterusan telah menyebabkan komposisi elemen utama yang didapati daripada air laut telah meningkat. Akibat daripada eksploitasi yang keterlaluan, kualiti air bawah tanah telah menunjukkan status yang tercemar. Analisis kimia ion utama menunjukkan yang kualiti air bawah tanah pulau tersebut telah mengalami perubahan yang disebabkan oleh penerobosan air laut. Kajian ini menunjukkan air bawah tanah terdiri daripada jenis Na-Cl dan Ca-Cl. Percampuran antara air laut dan air tawar telah dirumitkan oleh proses penukargantian kation yang diburukkan lagi oleh pengepaman air bawa tanah. Air bawah tanah ini didapati telah melalui proses perubahan komposisi daripada jenis kaya-Ca ke kaya-Na yang dapat diterangkan secara jelas melalui proses penukargantian kation. Kajian menunjukkan sebab utama kepada peningkatan kepekatan Na dan Cl bukan sahaja disebabkan oleh penerobosan air laut tetapi juga dipengaruhi oleh proses penukargantian kation yang pantas. Pekali korelasi yang kuat wujud antara elemen utama (Na, Mg, K, Cl dan  $SO_4$ ) dan parameter kemasinan antara/dengan kekonduksian elektrik (EC) menunjukkan kesan air laut ke atas elemen ini lebih signifikan disebabkan oleh wujudnya persaingan antara ion ini. Hubungkait ini membuktikan dengan jelas elemen utama yang menyumbang kepada kemasinan air bawah tanah dan kebolehannya untuk dipengaruhi kesan kemasinan yang sama. Daripada pengiraan PHREEQC, keterlarutan kalsit, dolomit dan aragonit menunjukkan nilai SI yang positif yang membawa kepada keadaan pembentukan mendakan oleh mineral tersebut. Eksploitasi yang berlebihan terhadap akuifer pulau Manukan telah mengubah keseimbangan semulajadi antara air tawar dan air laut dan menyebabkan peningkatan dalam kemasinannya dan seterusnya membawa kerumitan dalam hubungan antara air tawar dan air laut. Dapat diperhatikan juga bahawa percampuran air tawar dan air laut telah membawa kepada proses geokimia yang lebih kompleks serta telah mengubah percampuran proses percampuran air bawah tanah dan air laut jauh daripada teori percampuran. Ini menerangkan secara jelas proses yang mengambil tempat dalam penukargantian tersebut. Keputusan daripada simulasi pergerakan reaktif mengesahkan bahawa pergerakan air laut ke dalam akuifer air tawar telah membawa kepada proses pemendakan mineral-mineral karbonat. Keputusan simulasi juga menunjukkan bahawa komposisi keterlarutan ion-ion adalah berbeza antara kawasan yang hampir dengan persisir pantai dan jauh ke daratan yang mana mempengaruhi kesan penerobosan air laut ke atas komposisi akuifer.

**Kata kunci:** air bawah tanah, hidrokimia, PHREEQC, penerobosan air laut, pulau kecil

# CONTENTS

	<b>Page</b>
<b>TITLE</b>	i
<b>DECLARATION</b>	ii
<b>CERTIFICATION</b>	iii
<b>ACKNOWLEDGEMENTS</b>	iv
<b>ABSTRACT</b>	v
<b><i>ABSTRAK</i></b>	vi
<b>CONTENTS</b>	vii
<b>LIST OF TABLES</b>	xi
<b>LIST OF FIGURES AND PHOTOS</b>	xiv
<b>LIST PF ABBREAVIATIONS</b>	xx
<b>LIST OF SYMBOLS</b>	xxii
<b>LIST OF APPENDICES</b>	xxiv
<b>NOTES</b>	xxv
<b>CHAPTER 1 : INTRODUCTION</b>	<b>1</b>
1.1    Background	1
1.2    Thesis Outline	4
<b>CHAPTER 2 : LITERATURE REVIEW</b>	<b>5</b>
2.1    Statement of The Problems	5
2.2    Island Definition	8
2.2.1    High Islands	9
2.2.2    Low Islands	10
2.3    Water Resources of Small Islands	15
2.3.1    Other Water Sources	17
2.3.2    Surface Water	17
2.3.3    Groundwater	18
2.3.4    Natural Occurring of Groundwater in a Small Island	20
2.4    Seawater Intrusion	28
2.4.1    Brief Introduction	28
2.4.2    Review of Previous Studies on	35



	Seawater Intrusion	
2.5	Groundwater Geochemistry and Seawater Intrusion	44
2.5.1	Cation Exchange Process in the Seawater-Freshwater Mixing	45
2.5.2	pH Change in Mixed Waters and its Solubility Effects	52
2.5.3	Redox Processes	55
2.6	Natural Groundwater Quality Controls in Coastal Aquifers of Small Islands	58
2.7	The Use of Statistical Methods in Groundwater Geochemistry Study	61
2.8	Application of Hydrochemical Models to the Coastal Aquifer	63
2.8.1	General	63
2.8.2	PHREEQC	63
2.8.3	PHREEQC Application in Seawater Intrusion Studies	66
2.8.4	Advantages of Using PHREEQC	69
2.9	Summary	69
<b>CHAPTER 3 : OBJECTIVES AND SCOPE OF STUDY</b>		<b>71</b>
3.1	Objectives	71
3.2	Scope of Study	71
3.3	Significance of Study	72
<b>CHAPTER 4 : BACKGROUND OF STUDY AREA</b>		<b>74</b>
4.1	Location and Climate	74
4.2	Geology and Hydrogeology	80
4.3	Current Water Supply Status	86
<b>CHAPTER 5 : MATERIALS AND METHODS</b>		<b>87</b>
5.1	Samplings	87
5.1.1	Sampling Stations for General Hydrochemistry Survey	87
5.1.2	Sampling Stations for Hydrochemical Modeling Analysis	88
	(a) Installation of monitoring wells	88
	(b) Sediment Coring	91
	(c) Research limitation	92
5.1.3	Periods and Frequency of Samplings	92
5.1.4	Sampling Technique	92
5.1.5	Samples Preservation	93
5.2	Methods of Analyses	94
5.2.1	<i>In situ</i> Parameters Determination	94
5.2.2	Laboratory Analysis	95
5.2.3	Water Analysis	96
	(a) Sulfate	97

	(b) Chloride	97
	(c) Bicarbonate	97
	(d) Metals by Flame Atomic Absorption Spectrometry	98
	(e) Trace Elements by Inductively Coupled Plasma-Mass Spectrometry	100
5.2.4	Sediment Analysis	101
	(a) Cation Exchange Capacity and Exchangeable Cations	101
	(b) Water Content	103
5.2.5	Data Presentation	105
5.2.6	Statistical Analysis	105
5.2.7	Hydrochemical Calculation	107
	(a) Ionic Strength and Ionic Activities	108
	(b) Ion Complexes	109
	(c) Saturation Indices	110
5.2.8	Seawater Fraction	111
	(a) Fresh Groundwater Chemistry	112
	(b) Seawater Chemistry	112
5.2.9	Reactive Transport Modeling	112
<b>CHAPTER 6 : PART I</b>		115
	<b>OUTCOME OF THE HYDROCHEMICAL SURVEY</b>	
6.1	Background of Seawater Chemistry and Constituents	115
6.2	General Groundwater Physico-Chemical	116
6.3	Groundwater Major Ions Composition	123
6.4	Groundwater Trace Elements Constituent	131
6.5	Interpretation on Major Ions Constituent	140
	<b>PART II</b>	
	<b>SEAWATER-FRESH GROUNDWATER MIXING</b>	
6.6	Ionic Ratios for Delineating Salinity Sources	152
6.7	Ionic Strength and Ionic Activities	157
6.8	Ionic Changes in Fresh Groundwater Affected by Seawater Intrusion	165
6.9	Groundwater Saturation Indices and Ions Characteristics Contacts with Seawater	173
6.10	Characterization of Groundwater Hydrochemical System Using Multivariate Analysis	187
	6.10.1 Factor Analysis	188
	6.10.2 Cluster Analysis Using Factor Scores	196

<b>PART III</b>	199
<b>GROUNDWATER CHEMISTRY: REACTIVE TRANSPORT MODELING</b>	
6.11 Brief Introduction	199
6.12 Sediment Water Content	199
6.13 Water Table	200
6.14 Water Chemistry at the Seawater/Freshwater Mixing Zone	200
6.14.1 Groundwater Chloride and Salinity	201
6.14.2 Redox Species	203
6.14.3 Cation Exchange and CEC	205
6.14.4 Carbonate and Dolomite Minerals Saturation States	210
6.14.5 Reactive Transport Modeling	211
<b>CHAPTER 7 : CONCLUSIONS</b>	218
<b>CHAPTER 8 : RECOMMENDATIONS</b>	221
<b>REFERENCES</b>	226
<b>APPENDICES</b>	252



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## LIST OF TABLES

		Page
Table 2.1	Key characteristics of islands.	13
Table 2.2	Examples on seawater intrusion studies around the world.	36
Table 2.3	Comparison of groundwater chemical constituent levels in islands around the world.	38
Table 2.4	Methods applied in previous seawater intrusion studies conducted in small islands in Malaysia.	43
Table 2.5	Cation exchange capacity at pH 7 and their dependency.	47
Table 2.6	Important weak acidity reactions in natural water systems.	54
Table 2.7	Development progress of various PHREEQC versions.	65
Table 5.1	Locations coordinate of sampling stations in the study area based on Global Position System (GPS) readings.	87
Table 5.2	Locations coordinate of monitoring wells based on Global Position System (GPS) readings.	89
Table 5.3	Sample handlings and storage of groundwater samples	94
Table 5.4	List of parameters for <i>in situ</i> determination.	95
Table 5.5	List of apparatuses used during analyses.	95
Table 5.6	List of chemicals used for laboratory analyses.	96
Table 5.7	Summary of methods of analyses adopted in laboratory work.	96
Table 5.8	Preliminary samples treatment.	99
Table 5.9	The conditions for the detection of major ions in this study.	100
Table 5.10	The conditions for the detection of trace elements in this study.	101
Table 6.1	Water chemistry data of the coastal waters of Manukan island.	115
Table 6.2	Range of seawater composition in this study.	116

Table 6.3	The physico-chemical properties and major ions of groundwater in the study area (n =162).	117
Table 6.4	The comparison of physico-chemical properties of groundwater from several earlier island studies.	119
Table 6.5	Classification of saline groundwater.	120
Table 6.6	The concentrations of the analyzed constituents	125
Table 6.7	Ranges of the groundwater constituents of the study area and maximum permissible level by WHO (2004).	128
Table 6.8	Average concentrations of various trace elements in the groundwater of the studied area.	132
Table 6.9	Correlation coefficient matrix of the analyzed parameters.	134
Table 6.10	Results of the principle component factor analysis with Varimax rotation.	135
Table 6.11	Correlations among the major ions of the groundwater (n = 162).	140
Table 6.12	Summary of statistically computed two-way (between groups) ANOVA of the studied parameters.	142
Table 6.13	Water types encountered in the study area of Manukan island.	147
Table 6.14	The ionic composition of potential salinization sources.	153
Table 6.15	Comparison of ionic ratios of the studied seawater with other seawater data.	154
Table 6.16	Average ionic strength (M) and ionic activities of groundwater samples in the study area.	163
Table 6.17	Correlationship between the ionic species and ionic strength of the groundwater (n = 162).	165
Table 6.18	Fraction of seawater in Manukan island aquifer (meq/l).	167
Table 6.19	Changes in salinity and ionic strength as seawater is diluted by groundwater of salinity 0 ppt.	172
Table 6.20	SI of calcite, aragonite, dolomite and gypsum of the study area.	174

Table 6.21	$\frac{Ca_{we}}{Ca_{gw}}$ and $\frac{Mg_{we}}{Mg_{gw}}$ of the studied groundwaters in Manukan island.	183
Table 6.22	Eigenvalues greater than one, their percentage of variance and cumulative percentage of variance in the FA.	188
Table 6.23	Loadings for quatimax-rotated factor matrix for three factor model.	190
Table 6.24	The relationship between factor scores determined by FA and groups for each wells identified by CA.	197
Table 6.25	Water table elevation in the study area.	200
Table 6.26	Mean value of hydrochemical parameters for water samples from Manukan island	201
Table 6.27	Sources and processes responsible for high-salinity groundwater in coastal areas and associated chlorinity.	203
Table 6.28	Mean equivalent fractions ( $\beta$ ) of Na, K, Ca and Mg on the exchanger measured on core samples based on sampling points.	206
Table 6.29	Average saturation index for carbonate minerals and gypsum calculated with PHREEQC.	211
Table 6.30	Parameters for the PHREEQC 1-D reactive transport model.	213

## LIST OF FIGURES AND PHOTOS

		Page
Figure 2.1	The problem faced by small islands.	6
Figure 2.2	General barrier island cross-section.	10
Figure 2.3	Various stages in the geologic history of an atoll showing (a) active volcanic island, (b) volcanic core subsiding after cessation of volcanism, (c) final stages of volcanic rock a.m.s.l and (d) ring-like structure that characterizes most atolls.	12
Figure 2.4	Relationship between island fresh groundwater and sea.	14
Figure 2.5	Classification of subsurface water.	20
Figure 2.6	Sketch of perched water tables.	21
Figure 2.7	Small island freshwater lens.	23
Figure 2.8	Freshwater lens in a circular island.	24
Figure 2.9	Models of simple freshwater lenses. (a) Model with homogenous $K$ and $R$ . (b) Asymmetric lenses due to variability in $K$ (left) and $R$ (right). (c) Thinned lenses due to high $K$ layer at depth (left) and zero permeability $K$ layer at depth (right).	27
Figure 2.10	Groundwater flow in a marine island environment.	28
Figure 2.11	Schematic illustration of the relationship between the fresh groundwater lens and intruding seawater in a typical island setting.	29
Figure 2.12	Drawdown cone in freshwater lens of small island aquifer.	31
Figure 2.13	Several pathways of seawater intrusion into groundwater system. (a) Horizontal saltwater intrusion toward a supply well. (b) Induced downward movement of brackish surface water. (c) Saltwater upconing beneath supply well.	34
Figure 2.14	Schematic representation of chemical processes that influence the concentration of major ions in coastal area; (a) $\text{Na}^+$ , (b) $\text{Ca}^{2+}$ , (c) $\text{Mg}^{2+}$ .	49
Figure 2.15	Outline of the chemical processes responsible for various groundwater types.	51

Figure 2.16	Distribution of $\text{CO}_2$ , $\text{HCO}_3^-$ , $\text{CO}_3^{2-}$ system in pure water and seawater at 1 atm as a function of pH.	53
Figure 2.17	The stability of water the ranges of $Eh$ and pH conditions in natural environments.	57
Figure 2.18	Factors changing groundwater quality as a result of freshening or salinization.	60
Figure 4.1	Satellite image of locality of Manukan island.	75
Figure 4.2	Satellite image of Manukan island.	76
Figure 4.3	Manukan island and its surrounding features.	77
Figure 4.4	The annual total number of visitors on Manukan island for year 1997-2007.	78
Figure 4.5	Annual rainfall of the study area from 1995 to 2007.	79
Figure 4.6	Monthly rainfall data for study area from 1995 to 2007.	79
Figure 4.7	3-D elevation of the Manukan island.	81
Figure 4.8	The soil map of Kota Kinabalu and its surrounding area.	82
Figure 4.9	The soil profile of low and hilly relief areas at Manukan island.	84
Figure 4.10	The cross-section Y-X at Manukan island aquifer.	85
Figure 5.1	Location of Manukan island. Insert is sampling points located on the low lying area of the island.	88
Figure 5.2	Location monitoring wells (PZ) in the Manukan island.	90
Figure 5.3	Installation of multilevel nested monitoring wells at different depth in the study area.	90
Figure 5.4	Schematic diagram of boreholes constructed in Manukan island.	91
Figure 5.5	Flow of analyses for water content and CEC determination.	104
Figure 5.6	Flow chart for statistical analysis to data set.	107
Figure 5.7	Flow chart for speciation calculations.	111
Figure 6.1	(a) pH, (b) Eh, (c) EC, (d) Salinity and (e) TDS characteristics of groundwater for study location.	118



Figure 6.2	EC versus TDS plot for studied groundwaters (best fit line: $y = 759.9x$ ).	120
Figure 6.3	pH- <i>Eh</i> diagram for studied groundwater of Manukan island.	122
Figure 6.4	Box plots of major constituents in studied groundwater.	124
Figure 6.5	Cation diagram of groundwater samples from the study area.	126
Figure 6.6	Anion diagram of groundwater samples from the study area.	127
Figure 6.7	Major ions distribution based on WHO (2004) guidelines for (a) Ca, (b) Mg, (c) Na, (d) K, (e) Cl and (f) SO <sub>4</sub> .	129
Figure 6.8	Distribution of the major ions.	130
Figure 6.9	Trace elements distribution in the study area.	133
Figure 6.10	The relationship between average F1 score and salinity of groundwater.	136
Figure 6.11	Location of the sampling wells.	137
Figure 6.12	The relationship between average F2 score and pH of groundwater.	138
Figure 6.13	Schoeller diagram showing the concentration of major ions in the groundwater for March 2006.	143
Figure 6.14	Schoeller diagram showing the concentration of major ions in the groundwater for May 2006.	143
Figure 6.15	Schoeller diagram showing the concentration of major ions in the groundwater for July 2006.	144
Figure 6.16	Schoeller diagram showing the concentration of major ions in the groundwater for September 2006.	144
Figure 6.17	Schoeller diagram showing the concentration of major ions in the groundwater for November 2006.	145
Figure 6.18	Schoeller diagram showing the concentration of major ions in the groundwater for January 2007.	145
Figure 6.19	Piper plot for studied groundwater of Manukan island for March 2006.	148
Figure 6.20	Piper plot for studied groundwater of Manukan island for May 2006.	148

Figure 6.21	Piper plot for studied groundwater of Manukan island for July 2006.	149
Figure 6.22	Piper plot for studied groundwater of Manukan island for September 2006.	149
Figure 6.23	Piper plot for studied groundwater of Manukan island for November 2006.	150
Figure 6.24	Piper plot for studied groundwater of Manukan island for January 2007.	150
Figure 6.25	Overall Piper plot for studied groundwater of Manukan island.	151
Figure 6.26	Ionic ratio of Na/Cl versus Cl concentration (meq/l).	154
Figure 6.27	Ionic ratio of SO <sub>4</sub> /Cl versus Cl concentration (meq/l).	155
Figure 6.28	Ionic ratio of Cl/HCO <sub>3</sub> versus Cl concentration (meq/l).	156
Figure 6.29	Ionic strength vs TDS plot for the studied groundwater.	158
Figure 6.30	Distribution of ionic strength (M) in the unconfined aquifer of Manukan island for sampling episode of March 2006.	159
Figure 6.31	Distribution of ionic strength (M) in the unconfined aquifer of Manukan island for sampling episode of May 2006.	159
Figure 6.32	Distribution of ionic strength (M) in the unconfined aquifer of Manukan island for sampling episode of July 2006.	160
Figure 6.33	Distribution of ionic strength (M) in the unconfined aquifer of Manukan island for sampling episode of September 2006.	160
Figure 6.34	Distribution of ionic strength (M) in the unconfined aquifer of Manukan island for sampling episode of November 2006.	161
Figure 6.35	Distribution of ionic strength (M) in the unconfined aquifer of Manukan island for sampling episode of January 2007.	161
Figure 6.36	Ionic strength and ion activity for major ions of (a) Ca, (b) Mg, (c) Na, (d) K, (e) HCO <sub>3</sub> (f) Cl and (g) SO <sub>4</sub> .	164
Figure 6.37	Ionic changes ( $e_{\text{change}}$ ) of groundwater samples from Manukan island.	169
Figure 6.38	$e_{\text{change}}$ for Na(a), K(b), Ca(c) and Mg(d) for the samples taken in March'06 to January'07.	171

Figure 6.39	Relationship between ionic strength and % of seawater.	172
Figure 6.40	Relationship between simulated and field data that plotted with theoretical line 1:1.	173
Figure 6.41	Average SI trends of selected minerals over sampling periods.	175
Figure 6.42	Saturation indices plot for calcite and dolomite.	176
Figure 6.43	(a) Calcite, (b) Aragonite (c) Dolomite (d) Gypsum saturation indices of studied groundwaters with the theoretical saturation indices for conservative mixing between seawater and freshwater.	177
Figure 6.44	Plot of SI for selected mineral species; (a) calcite, (b) aragonite and (d) dolomite.	178
Figure 6.45	SI plot of aragonite versus Na concentration (mg/l) over time.	179
Figure 6.46	Mg/Ca plot over % seawater (ion values in meq/l).	181
Figure 6.47	Average saturation states of calcite, aragonite and dolomite with respect to $Ca_{we}/Ca_{gw}$ and $Mg_{we}/Mg_{gw}$ .	184
Figure 6.48	SI plot for gypsum over calcite.	186
Figure 6.49	Scree plot for each component numbers for studied groundwater.	189
Figure 6.50	Spatial distributions of scores of (a) Factor 1, (b) Factor 2 and (c) Factor 3.	191
Figure 6.51	Results of factor scores of Manukan island's groundwater.	193
Figure 6.52	Relationship between F1 score and salinity for the studied groundwater.	193
Figure 6.53	The relationship between average F3 score and Eh of groundwater.	195
Figure 6.54	Dendrogram groups of sampling stations determined in CA.	196
Figure 6.55	Results of clustering shown by sampling points.	198
Figure 6.56	Graph of the observed (a) Cl concentration and (b) Salinity vs. distance from the coast (n = 21).	202

Figure 6.57	Graph of the observed SO <sub>4</sub> vs. distance from the coast (n = 21).	204
Figure 6.58	CEC vs Na exchangeable cation content.	205
Figure 6.59	Equivalent fractions distributions of major ions along the transects.	207
Figure 6.60	Equivalent fractions of (a) Na and (b) Ca on the exchanger measured on core samples (solid symbols) and calculated using PHREEQC from the groundwater composition (dashed lines).	208
Figure 6.61	Monitoring wells position and different zones of solution.	212
Figure 6.62	Observed distributions (solid symbols) along flow path from coast of: (a) Cl, (b) HCO <sub>3</sub> , (c) Na, (d) K, (e) Ca and (f) Mg (all in mmol/l). Dashed lines are modeled distributions using PHREEQC with 15% of diluted seawater mix with fresh groundwater.	214
Figure 6.63	Overall modeled distributions using PHREEQC.	216
Photo 1	Water tanks situated on the hill	253
Photo 2	PK 1, PK 2 and PK 3 wells in Manukan island.	254
Photo 3	PK 4, PK 5 and PK 6 wells in Manukan island.	255
Photo 4	PK 7, PK 8 and PK 9 wells in Manukan island.	256
Photo 5	Monitoring well constructed with PVC with insert showing the close up.	257
Photo 6	Hand auger used in this study	258
Photo 7	Sediment coring	259
Photo 8	Sediment sample collection	260
Photo 9	Monitoring well installation	260
Photo 10	Groundwater sample abstraction	261
Photo 11	Water level meter for groundwater level measurement	262

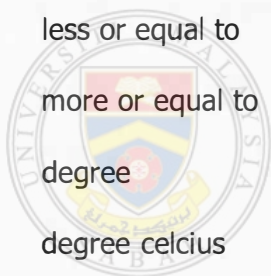
## LIST OF ABBREVIATIONS

1-D	one dimensional
3-D	three dimensional
a.m.s.l	above mean sea level
a.s.l	above sea level
APHA	American Public Health Association
CA	Cluster analysis
CEC	cation exchange capacity
CV	coefficient of variance
DGH	Dupuit Ghyben Herzberg
DO	dissolved oxygen
EC	electrical conductivity
<i>Eh</i>	redox potential
EIA	Environmental Impact Assessments
FA	factor analysis
FAAS	Flame Atomic Absorption Spectrometry
g.s.l	ground surface level
I.S	Ionic strength
IAP	ion activity product
ICP-MS	Inductively Couple Plasma – Mass Spectrometry
IWRM	Integrated Water Resources Management
KKIA	Kota Kinabalu International Airport
n	Number (number of samples)
NASA	National Aeronautics and Space Administration
NEMI	National Environmental Index

NIST	National Institute of Standards and Technology
ORP	oxidation reduction potential
PVC	polyvinyl chloride
R-mode	R-mode
rpm	rotation per minute
SD	standard deviation
SI	saturation index(ices)
SPSS	Statistical Analysis for Social Sciences
SRM	standard reference materials
SRTM	Shuttle Radar Topographic Mission
TDS	total dissolved solids
Temp.	temperature
UKM	Universiti Kebangsaan Malaysia
UMS	Universiti Malaysia Sabah
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organization
UPM	Universiti Putra Malaysia
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
USA	United States of America
WHO	World Health Organization

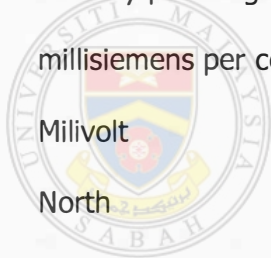
## LIST OF SYMBOLS

-	negative / minus
%	percent
~	approximately
'	minute
+	positive / plus
<	not more than
=	equals to
>	more than
±	plus minus
≤	less or equal to
≥	more or equal to
°	degree
°C	degree celcius
µg/l	microgram per liter
µm	micrometer
µS/cm	microsiemens per centimeter
atm	atmosphere
cm	centimeter
E	East
<i>ET</i>	evapotranspiration
g	gram
g/cm <sup>3</sup>	gram per cubic centimeter
g/kg	gram per kilogram
J/mol K	Joule per molality Kelvin



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$K$	hydraulic conductivity
km	kilometer
m	meter
M	molar
$m^2$	square meter
$m^2/s$	square meter per second
meq/100 g	milliequivalent per hundred gram
mg/l	milligram per liter
ml	milliliter
mm	millimeter
mmol/l	millimolar per liter
mol/kg	molality per kilogram
mS/cm	millisiemens per centimeter
mV	Milivolt
N	North
$P$	precipitation
$p$	significant value
ppt	part per thousand
$R$	recharge
$r$	correlation value
V	voltan
yr	year
$\beta$	equivalent fraction
$\rho$	density
$\Sigma$	Sum



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