

**HYDROGEOCHEMISTRY OF SHALLOW
AQUIFER, MANUKAN ISLAND, SABAH**



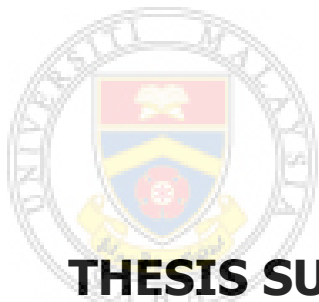
LIN CHIN YIK

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**SCHOOL OF SCIENCE AND TECHNOLOGY
UNIVERSITI MALAYSIA SABAH
2011**

**HYDROGEOCHEMISTRY OF SHALLOW
AQUIFER, MANUKAN ISLAND, SABAH**

LIN CHIN YIK



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**THESIS SUBMITTED IN FULFILLMENT
FOR THE DEGREE OF MASTER OF SCIENCE**

**SCHOOL OF SCIENCE AND TECHNOLOGY
UNIVERSITI MALAYSIA SABAH
2011**

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DECLARATION

I hereby declare that this dissertation is an effort of my own except for the quoting and references whereby its sources were clarified and stated clearly.

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ABSTRACT

HYDROGEOCHEMISTRY OF SHALLOW AQUIFER, MANUKAN ISLAND, SABAH

A total of 180 shallow groundwater samples in Manukan island's aquifer were collected for major and trace elements analysis in order to obtain a general understanding of the hydrogeochemistry in the study area. Groundwater and soil samples were collected in the low elevation area of the island to evaluate the general chemical composition of groundwater and soil, hydrogeochemical facies in the natural shallow aquifer as well as the mineralogy of the soil in the aquifer. A total of 10 boreholes were installed perpendicularly from the shoreline towards inland of the island. Different layer (O, A, E, B and C zone) of soil samples were collected from the soil core during coring process. For water samples analysis, *in situ* readings were recorded in the field. Chemical parameters such as chloride (Cl^-), bicarbonate (HCO_3^-), calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+) and potassium (K^+) were analysed in the laboratory. For mineralogy analysis, soil samples were pulverized and sieved prior to X-ray diffraction (XRD) and X-ray Florescence (XRF) analysis. Visual verification of these minerals were obtained from the images captured by scanning electron microscopy (SEM). Measurements of the soil's loss on ignition (L.O.I.) and total metals in the soil samples were also included in the results, respectively. The results indicate that the groundwater collected from the boreholes were moderately mineralized with EC ranged from 460 $\mu\text{S}/\text{cm}$ to 3400 $\mu\text{S}/\text{cm}$. The previous indiscriminate pumping activities had led to seawater intrusion into the aquifer. This study shows that the groundwater were generally classified as Ca- HCO_3 , CaCl_2 , NaHCO_3 and NaCl water type as illustrated in the Piper diagrams. This study also found that the PHREEQC calculations were in agreement with the soil geochemical composition data. The PHREEQC calculations for calcite, aragonite and dolomite solubility revealed positive values in the saturation indices (SI), indicating supersaturated state i.e. precipitation shall occur with respect to these minerals. The baseline geochemical results clearly revealed that the major chemical composition of the soil in the study area was mainly composed of quartz, calcite, aragonite as well as magnesium calcite. XRF analysis depicts a general trend where the soil chemical composition varies significantly with depth and distance from shore. The composition of calcium oxides increases with depth. Conversely, silicon oxide showed a decreasing trend in composition with increasing depth which dominated by carbonates minerals. SEM images visually showed the presence of quartz, calcite and aragonite minerals in the soil samples and further supports the data obtained from XRD.

Keywords: Hydrogeochemistry, small island, shallow groundwater, geochemical composition, soil mineralogy.

ABSTRAK

Sejumlah 180 sampel air bawah tanah di akuifer cetek Pulau Manukan telah diambil bagi menentukan unsur-unsur utama dan surih untuk memahami hidrogeokimia dalam kawasan kajian tersebut. Air bawah tanah dan sampel-sampel tanah dikutip di kawasan rendah pulau untuk dinilai komposisi kimia air dan tanah secara umum, fasis hidrogeokimia dalam akuifer cetek yang semulajadi serta mineralogi tanah di akuifer tersebut. Sejumlah 10 telaga cerapan telah dibina secara menegak dari tepi pantai menuju ke arah kawasan di dalam pulau tersebut. Lapisan tanah yang berbeza (zon O, A, E, B dan C) telah disampelkan dari teras tanah semasa proses pengerudian. Untuk analisis sampel-sampel air, parameter *in situ* telah dicatatkan di lapangan. Parameter-parameter kimia seperti klorida (Cl^-), bikarbonat (HCO_3^-), kalsium (Ca^{2+}), magnesium (Mg^{2+}), natrium (Na^+) dan kalium (K^+) dianalisis dalam makmal. Bagi analisis mineralogi pula, sampel tanah telah dikisar dan diayak sebelum dianalisis dengan kaedah pembelauan sinar-X (XRD) dan pendaflour sinar-X (XRF). Pengesahan mineral sampel tanah secara visual dilakukan dengan menggunakan mikroskop elektron imbasan (SEM). Pengukuran LOI tanah dan jumlah logam dalam sampel tanah juga dimasukkan dalam keputusan masing-masing. Hasil keputusan menunjukkan bahawa air bawah tanah yang disampelkan dari semua telaga cerapan itu mempunyai kandungan mineral yang sederhana tinggi di mana EC berjudat dari $460 \mu S / cm$ hingga $3400 \mu S / cm$. Aktiviti pengepaman air bawah tanah secara berterusan sebelum ini telah menyebabkan penerobosan air laut ke dalam akuifer. Kajian ini menunjukkan bahawa air bawah tanah pada umumnya diklasifikasikan sebagai jenis air $Ca-HCO_3$, $CaCl_2$, $NaHCO_3$ dan $NaCl$ seperti ditunjukkan oleh gambarajah Piper. Kajian ini juga mendapati bahawa hasil pengiraan model PHREEQC sesuai dengan komposisi geokimia tanah. Pengiraan PHREEQC untuk keterlarutan kalsit, aragonit dan dolomit menunjukkan nilai-nilai positif dalam indeks ketepuan (SI), yakni berlaku pemendakan pada mineral-mineral tersebut. Keputusan geokimia awal telah jelas menunjukkan bahawa komposisi kimia tanah dalam kawasan kajian adalah terdiri daripada mineral-mineral kuarza, kalsit, aragonit serta magnesium berkalsit. Analisis XRF telah menggambarkan satu trend umum di mana komposisi kimia tanah berubah mengikut kedalaman serta jarak dari laut. Komposisi kalsium oksida meningkat mengikut kedalaman. Sebaliknya, silikon oksida mengurang dalam komposisi apabila kedalaman bertambah disebabkan oleh kandungan mineral karbonat yang mendominasi pada kedalaman tersebut. Imej-imej SEM secara visual menunjukkan kehadiran mineral-mineral kuarza, kalsit dan aragonit dalam sampel tanah itu dan telah berjaya menyokong keputusan-keputusan yang diperolehi oleh XRD.

Katakunci: Hidrogeokimia, pulau kecil, air bawah tanah cetek, komposisi geokimia, mineralogi tanah.

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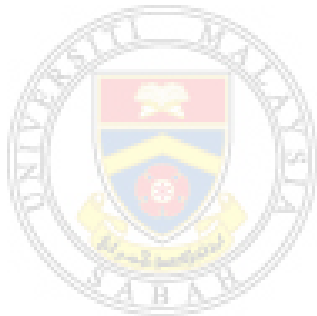
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LIST OF ABBREVIATIONS

AAS	Atomic Absorption Spectrometry
AMSL	Above Mean Sea Level
APHA	American Public Health Association
Dca	Carbonate Deposits
DO	Dissolved Oxygen
EC	Electrical Conductivity
GPS	Global Positioning System
HMC	High Magnesium Calcite
IAP	Ion Activity Product
ICP	Inductively Coupled Plasma
LMC	Low Magnesium Calcite
MSL	Mean Sea Level
N/A	Not Available
OM	Organic Matter
ORP	Oxidation Reduction Potential
PHE	Potentially Hazardous Elements
SEM	Scanning Electron Microscope
SHE	Standard Hydrogen Electrode
SI	Saturation Indices
SPSS	Statistical Package for Social Science
SS	Suspended Solids
TDS	Total Dissolved Solids
UMS	Universiti Malaysia Sabah
US EPA	United States Environmental Protection Agency
USGS	United States Geological Survey
VES	Vertical Electrical Sounding
WHO	World Health Organization
XRD	X-Ray Diffraction
XRF	X-Ray Fluorescence

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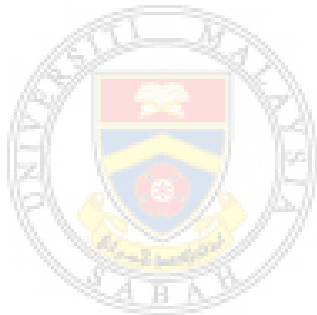
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LIST OF SYMBOLS

%	percent
<	not more than
>	more than
≈	approximately
° C	degrees Celsius
μl	micro liter
μm	micro meter
μScm ⁻¹	micro Siemens per centimeter
km	kilometer
km ²	square meter
km ³	cubic kilometer
m	meter
m ²	square meter
m ³	cubic meter
meq ⁻¹	milliequivalent per liter
mg ⁻¹	milligram per liter
ml	milliliter
nm	nanometer
mm	millimeter
cm	centimeter
ft	feet
ppm	part per million
ppt	part per thousand
N	North
S	South
E	East
W	West

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CHAPTER 1

INTRODUCTION

Groundwater provides an important source of drinking water over the world. Being the largest reserve of drinkable water for human population, groundwater has always been of major importance to human civilization. Compared with other kinds of water, groundwater is normally preferred because it tends to be less contaminated directly by wastes and organisms (Tariq *et al.*, 2008). However, groundwater is under threat worldwide from over abstraction and by contamination from a wide range of human activities (Brassington, 2007). Accordingly, seawater intrusion is a common phenomenon in the coastal aquifers and small islands. Small island specifically with permeable sedimentary formation is particularly vulnerable to seawater contamination (Abdullah *et al.*, 1997). Manukan island is not an exception because it is a small tropical coral island deposited by permeable loose soil derived from sedimentary formation which lies within the coastal belt. Additionally, the aquifer of Manukan island is largely unconfined and thus prone to seawater intrusion (Shammas and Jacks, 2007). Hence, Manukan island was selected as the study area in this research.

Owing to the fact that groundwater is in close contact with the underlying soil and rock material, mineral compositions of soil will be leached out progressively (Pelig-Ba, 1998). According to Essington (2004), many of the environmentally problematic elements occur in uncontaminated soils in very low concentrations. These elements are commonly referred to as trace element or heavy metals. Soil contamination sources might be varies from natural bedrock dissolution to anthropogenic seawater intrusion. In nature, soil acts as a natural filter to screen out many contaminants that mix with the water. However, the soil's ability to filter contaminants is rather limited. Instead, soil can also act as sources for metals contaminations where metals can be released into the water phase when conditions such as pH, redox potential, ionic strength, and the concentration of organic complexing agents are appropriate (Calmano *et al.*, 1990). There are many

reactions occurring (e.g. precipitation, dissolution, speciation changes, etc.) particularly in the fresh water-seawater transition zone from the changes in pH, redox, and chemistry that may affect the groundwater chemistry in a very short time (Varsanyi and Kovacs, 1997; Dowling *et al.*, 2003). Dowling *et al.*, (2003) further concluded that the presence of coastal soil also influence the groundwater chemistry through sediment permeability, cation exchange, and adsorption and desorption reactions. Now we know, these complex processes are likely to control the distribution of trace elements in groundwater, which typically has a large range of chemical composition (Hem, 1970, Drever, 1982; Appelo and Postma, 2005). Generally, the trace element composition of groundwater depends not only on natural sources such as lithology of the aquifer, the quality of recharge waters and the types of interaction between water and aquifer, but in certain circumstances also on anthropogenic sources such as human activities, which can alter these fragile groundwater systems, either by polluting them or by changing the hydrological cycle (Helena *et al.*, 2000; Newcomba *et al.*, 2002; Abollino *et al.*, 2004; Leung and Jiao, 2006; Jalali, 2008).

Currently, there is a growing concern over the potential accumulation of trace elements concentration in groundwater of coastal aquifer owing to seawater encroachment in the last decades (Mondal *et al.*, 2009). A lot of works have been done worldwide in this field in the Atlantic and Pacific. For examples, Dodge and Brass (1984) and Madkour (2005) have documented the increase of lead (Pb) levels in both coral reef of Virgin Island and Wadi El-Gemal with time due to the increase in lead availability from global pollution. Xie *et al.* (2005) reported that the contamination of groundwater of Coral Island (Xi Sha Island in South China Sea) is due to saltwater intrusion, leaching of heavy metals, and toxic elements from granitic rock and guano-soil, respectively. Analysis of groundwater from some crystalline rocks in the upper region of Ghana indicated that most trace elements (Al, Fe, Zn, Sr, and Ba) were excessively higher in natural water systems (Pelig-Ba, 1998). A large number of researchers have also worked on trace element contents of groundwater in the Indian subcontinent and along its coastal area. Ramesh *et al.* (1995) revealed that the toxic element (As and Se) and other trace elements in groundwater of Madras City are due to anthropogenic activities and saltwater