



Faculty of Resource Science and Technology

**GROUNDWATER GEOCHEMISTRY OF THE  
"KAYAN SANDSTONE" AQUIFER IN THE LUNDU  
AREA OF WESTERN SARAWAK**

Tamizy Bin Ibrahim

Bachelor of Science with Honours  
(Resource Chemistry)  
2004

TN  
270  
T153  
2004

**GROUNDWATER GEOCHEMISTRY OF THE "KAYAN SANDSTONE"**

**AQUIFER IN THE LUNDU AREA OF WESTERN SARAWAK**

P.KHIDMAT MAKLUMAT AKADEMIK  
UNIMAS



1000126523

TAMIZY BIN IBRAHIM

This project is submitted in partial fulfillment of the requirements for the degree of  
Bachelor of Science with Honours  
(Resource Chemistry)

Faculty of Resource Science and Technology  
UNIVERSITI MALAYSIA SARAWAK  
2004

- Geochemistry
- Geochemical prospecting

## DECLARATION

No portion of the work referred to in this dissertation has been submitted in support of an application for another degree of qualification of this or any other university or institution of higher learning.



.....  
**Tamizy bin Ibrahim**  
Program of Resource Chemistry  
Faculty of Resource Science and Technology  
Universiti Malaysia Sarawak

## ACKNOWLEDGEMENTS

I would like to thank the all those who have helped me in completing this project. I wish to thank the Jabatan Pendidikan Negeri Sarawak especially Mr. Poniman Bejok, as well as, the headmaster of Sekolah Kebangsaan Stungkor, En. Haji Sarbini for their permission to carry out the sampling. I also like to thank the Jabatan Mineral and Geosains especially Mr. Yusuf Bujang for his advice on water chemistry and water quality. I am specially grateful to my project supervisor, Dr. Harwant Singh for his help. Finally, I am indebted to all my friends especially Briony Octavia Homer Mun, Dyg. Sherrynazra bt. Awg. Sharkawi and Cynthia Rawlin Roney and my family for their help and encouragement.

## TABLE OF CONTENTS

<b>DECLARATION</b>		ii
<b>ACKNOWLEDGEMENTS</b>		iii
<b>TABLE OF CONTENTS</b>		iv
<b>LIST OF FIGURES</b>		vi
<b>LIST OF TABLES</b>		vii
<b>ABSTRACT</b>		viii
<b>ABSTRAK</b>		ix
<b>CHAPTER ONE</b>	<b>INTRODUCTION</b>	1
1.1	Background	
1.1.1	Occurrence of Groundwater	1
1.1.2	Importance of Groundwater in Sarawak	1
1.1.3	Origins of Groundwater	1
1.1.4	Rock Properties Affecting Groundwater	2
1.2	Objectives	2
<b>CHAPTER TWO</b>	<b>LITERATURE REVIEW</b>	3
2.1	Geochemistry of Groundwater in Sedimentary Rocks	
2.1.1	Major Ion Composition	3
2.1.2	Chemical Processes Occurring in Groundwater	3
2.1.3	Chemical Constituents in Groundwater	4
2.2	Geology of the Study Area	5
2.3	Previous Groundwater Analysis from the Kayan Sandstone Aquifer	7

<b>CHAPTER THREE MATERIALS AND METHODS</b>	<b>8</b>
3.1 Materials	8
3.2 Sampling Program	8
3.3 Sample Collection	8
3.4 Sample Preservation	8
3.5 Parameters Measured	9
<b>CHAPTER FOUR RESULTS AND DISCUSSION</b>	<b>10</b>
4.1 Results of the groundwater analysis	10
4.2 Charge Balance	12
4.3 Comparison with Hydrogeochemical Data from the Kayan Sandstone from Literature	
4.3.1 Vertical Bar Diagrams for the Hydrogeochemical Analyses	13
4.3.2 Stiff Diagrams Representing the Hydrogeochemical Data	18
4.4 Monthly Comparisons	20
4.5 Hydrochemical Facies of the Groundwater	22
4.6 Hardness	25
4.7 Groundwater Quality	25
<b>CHAPTER FIVE CONCLUSION</b>	<b>27</b>
<b>REFERENCES</b>	

## LIST OF FIGURES

Figure 1	Distribution of the Kayan Sandstone (Tan, 1993)	6
Figure 2	Analysis L1	13
Figure 3	Analysis L2	13
Figure 4	Analysis L3	14
Figure 5	Analysis L4	14
Figure 6	Analysis S1 (September)	15
Figure 7	Analysis S2 (October)	15
Figure 8	Analysis S3 (November)	16
Figure 9	Analysis S4 (December)	16
Figure 10	Analysis S5 (January)	17
Figure 11	Analysis S6 (February)	17
Figure 12	Stiff diagram for S1 – S6	18
Figure 13	Stiff diagram for L1 – L4	19
Figure 14	Monthly groundwater cation concentrations	20
Figure 15	Monthly groundwater anion concentrations	21
Figure 16	Classification of the groundwater water from in this investigation	23
Figure 17	Groundwater Classification of Selected Chemical Analysis from Kayan Sandstone Formation.	24

## LIST OF TABLES

Table 1	Chemical Analyses of Groundwater from a Sandstone Aquifer (White <i>et al.</i> , 1980)	3
Table 2	The Sources of the Principal Chemical Constituents in Groundwater (Todd, 1980)	5
Table 3	Selected Previous Chemical Analysis from the Kayan Sandstone Aquifer	7
Table 4	U.S. EPA Required Preservation Methods for Water (U.S. EPA, 1983)	9
Table 5	Results of Groundwater Analyses	11
Table 6	Charge Balance Results from Analyses Reported in Literature	12
Table 7	Hardness Classification of Water (after Sawyer and McCarty, 1967)	25
Table 8	Quality Classification of Water for Irrigation (from Todd, 1980)	26



## ABSTRACT

A groundwater study was done to determine the geochemistry of groundwater of a Sandstone Aquifer in the Lundu Area in Western Sarawak. The major chemical constituents i.e. cations and anions and other parameters were analyzed for six months to determine their concentrations, to detect temporal variations, to determine the quality of the groundwater and detect any contamination. The samples were collected once in a month beginning in September 2003 until February 2004. The chemical composition of the samples analyzed for each month was found to be the same having similar chemical concentrations so these were found not to change over time. From this study, the investigated groundwater can be classified as 'calcium bicarbonate' water. The water quality is generally good and well within the W.H.O. Standard for drinking water and good for irrigation purposes. The nitrate concentration is very low under the recommended limit so the groundwater was not polluted by wastes or fertilizers applied to the land surface. However, to make this water more suitable for domestic use, further treatment is needed.

Key words: Groundwater, hydrogeochemistry, groundwater type, water quality.

## ABSTRAK

*Kajian air bawah tanah dilakukan untuk menentukan geokimia air bawah tanah dari akuifer batu pasir di kawasan Lundu, di bahagian Barat Sarawak. Ion-ion kimia utama seperti kation dan anion dan parameter yang lain telah dianalisis selama enam bulan untuk menentukan kepekatan ion-ion kimia utama, mengesan variasi temporary, menentukan kualiti air bawah tanah dan mengesan kewujudan pencemaran terhadap air bawah tanah tersebut. Sampel-sampel telah diambil setiap bulan bermula dari September 2003 sehingga Februari 2004. Komposisi kimia sampel-sampel yang dianalisis setiap bulan didapati dengan trend yang serupa dengan mempunyai kepekatan ion yang hampir sama, oleh itu didapati komposisi kimia tidak berubah dengan masa. Kajian ini menunjukkan air bawah tanah ini boleh diklasifikasikan sebagai air 'kalsium bikarbonat'. Kualiti air secara umumnya baik di bawah Standard W.H.O sebagai air minuman dan baik untuk kegunaan pengaliran. Kepekatan ion nitrat adalah sangat rendah di bawah had saranan dan air bawah tanah ini dikenalpasti tidak dicemari oleh bahan-bahan sisa buangan atau baja-baja tumbuhan. Walaubagaimanapun, untuk membuatkan air tersebut lebih sesuai untuk kegunaan domestik, rawatan selanjutnya diperlukan.*

*Kata kunci: Air bawah tanah, geokimia air, jenis air bawah tanah, kualiti air.*

# CHAPTER ONE

## INTRODUCTION

### 1.1 Background

#### 1.1.1 Occurrence of Groundwater

The earth's crust is made up of rocks and covered by soil. Rocks contain openings called pores or voids. This property of rock of possessing pores or voids is called porosity (Price, 1996). The porosity is of fundamental importance for groundwater as these pores or voids contain water. This water is called groundwater. The unsaturated zone consists of voids occupied partially by water and partially by air. In the zone of saturation, all the voids are filled with water.

#### 1.1.2 Importance of Groundwater in Sarawak

Groundwater has become a very essential source of water especially in the coastal lowlands of Sarawak since the 1980s. The reliance on groundwater is apparent, as 30% of the water supply is dependent on groundwater [Department of Environment Malaysia (DoE), 2002].

#### 1.1.3 Origins of Groundwater

According to Price (1996) there are three possible origins for groundwater. They are *meteoric water*, *connate water* and *juvenile water*. The groundwater derived from rainfall and infiltration within the normal hydrological cycle is referred to as *meteoric water*. The water encountered at great depth in sedimentary rocks thought to have originated as sea water trapped in marine sediments at the time of deposition, generally saline water, is referred as a

*connate water*. *Juvenile water* is water that is derived from igneous processes within the earth and which can contribute unusual constituents to the *meteoric water*.

#### **1.1.4 Rock Properties Affecting Groundwater**

The property of possessing pores or voids of a rock is called its porosity. These pores are fundamental importance to the study of groundwater. The permeability of a rock defines its ability to transmit a fluid. Layers of rock sufficiently porous to store water and permeable enough to allow water to flow through them in economic quantities are call aquifers (Price, 1996).

#### **1.2 Objectives**

The objectives of this study are to determine the various major chemical constituents in the groundwater and their concentrations, to classify the chemical constituents in terms of major-ion percentages, to detect temporal variations in the major chemical constituents and to determine the quality of the groundwater and detect any contamination in a sedimentary aquifer located in western Sarawak, namely, the “Kayan” Sandstone.

## CHAPTER TWO

### LITERATURE REVIEW

#### 2.1 Geochemistry of Groundwater in Sedimentary Rocks

##### 2.1.1 Major Ion Composition

The major anions and cations in groundwater are nearly the same as the anions and cations that are present in rainwater (Freeze and Cherry, 1979). The constituents that are always reported are  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^+$  and  $\text{K}^+$  for cations and  $\text{HCO}_3^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{Cl}^-$  and  $\text{NO}_3^-$  for anions (Freeze and Cherry, 1979). Table 1 shows the hydrogeochemistry of a sandstone aquifer.

Table 1 Chemical Analyses of Groundwater from a Sandstone Aquifer (White *et al.*, 1980)

Chemical Constituents	Concentration, mg/L
$\text{Ca}^{2+}$	44.00
$\text{Mg}^{2+}$	11.00
$\text{Na}^+$	60.00
$\text{K}^+$	4.10
$\text{HCO}_3^-$	327.00
$\text{CO}_3^{2-}$	0.00
$\text{SO}_4^{2-}$	22.00
$\text{Cl}^-$	4.40
$\text{NO}_3^-$	2.00
Specific Conductance	533
pH	7.4

##### 2.1.2 Chemical Processes Occurring in Groundwater

Mandel and Shiftan (1981) reported that there are five major chemical processes occurring between groundwater and rocks. The chemical processes are dissolution and precipitation, ion exchange, mixing, oxidation and reduction and membrane effects. As groundwater moves through rocks it tends to interact with them and as a consequence chemical

reactions result. Chemical precipitation may also remove ions in solution by forming insoluble compounds (Todd, 1980). Ion exchange involves the replacement of ions adsorbed on surface of fine-grained materials in aquifers by ions in solutions (Todd, 1980). Because the exchange involves principally cations, the process is also known as base, or cation exchange. Mixing of groundwater bodies with different chemical composition is a result of two physical processes namely diffusion and hydrodynamic dispersion (Mandel and Shiftan, 1981). Diffusion is caused by the thermal motion of molecules and ions while hydrodynamic dispersion is caused by flow through a network of interconnected channels. Redox reactions i.e. oxidation and reduction occurring simultaneously occur in the subsurface. There are three types of redox reactions which frequently occur in groundwater i.e. nitrification and denitrification, oxidation of sulfides to sulfates and the reduction of sulfates to molecular sulfur and sulfide, and the oxidation of bivalent iron to trivalent iron (Mandel and Shiftan, 1981). Mandel and Shiftan (1981) suggested that membrane effects in terms of osmotic diffusion, may occur where a clay layer separates freshwater from saline water.

### **2.1.3 Chemical Constituents in Groundwater**

The dissolution, availability and solubility of minerals commonly influenced the major ion composition. Important minerals in the sedimentary rocks furnish a major portion of the soluble constituents to groundwater (Todd, 1980). The sources of the principal chemical constituents are given in Table 2.

**Table 2 The Sources of the Principal Chemical Constituents in Groundwater (Todd, 1980).**

Constituent	Major Natural Sources
Calcium ion ( $\text{Ca}^{2+}$ )	Amphiboles, feldspars, gypsum, pyroxenes, aragonite, calcite, dolomite, clay minerals.
Magnesium ion ( $\text{Mg}^{2+}$ )	Amphiboles, olivine, pyroxenes, dolomite, magnesite, clay minerals.
Sodium ion ( $\text{Na}^+$ )	Feldspars (albite); clay minerals; evaporates, such as halite ( $\text{NaCl}$ ) and mirabilite ( $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$ ); industrial wastes.
Potassium ion ( $\text{K}^+$ )	Feldspar (orthoclase and microcline), feldspathoids, some micas, clay
Carbonate ion ( $\text{CO}_3^{2-}$ )	Limestone, dolomite
Bicarbonate ion ( $\text{HCO}_3^-$ )	Limestone, dolomite
Sulfate ion ( $\text{SO}_4^{2-}$ )	Oxidations of sulfide ores; gypsum; anhydrite
Chloride ion ( $\text{Cl}^-$ )	Chief source is sedimentary rock (evaporates); minor sources are igneous rocks
Nitrate ion ( $\text{NO}_3^-$ )	Atmosphere; legumes, plant debris, animal excrement

## 2.2 Geology of the Study Area

The study area is located within the "Kayan" Sandstone shown in Figure 1 which consists of thick bedded sandstone intercalated with siltstone, shale, mudstone and rare lenses of limestone. Generally, the sandstone is gray in colour, moderately hard and fine-medium grained and fall in quartzose subgraywacke class, containing between 10 and 25 percent of rock fragment and feldspar (Wolfenden, 1963).

The "Kayan" Sandstone in the Sematan-Lundu area is estimated to be about 1,500 m thick in the "Kayan" valley and between 760 m and 910 m thick in the Samunsan valley (Wolfenden, 1963), overlying with slight angular unconformity on the Pedawan Formation. The eroded uppers part of the "Kayan" Sandstone Formation, are in places overlain

unconformably by Recent alluvium (Tan, 1993). The "Kayan" Sandstone is a sedimentary sandstone aquifer.



Figure 1 Distribution of the Kayan Sandstone (Tan, 1993)



### 2.3 Previous Groundwater Analysis from the “Kayan” Sandstone Aquifer

Results of hydrogeochemical investigations carried out at different locations in this aquifer were available from literature. The result of the groundwater chemical analysis from these investigations is given in the Table 3 below.

**Table 3 Selected Previous Chemical Analysis from the “Kayan” Sandstone Aquifer.**

Analysis		L1 <sup>a</sup>	L2 <sup>a</sup>	L3 <sup>a</sup>	L4 <sup>a</sup>
		A <sup>b</sup>	B <sup>b</sup>	C <sup>b</sup>	D <sup>b</sup>
Parameter					
pH		8.6	6.9	6.3	7.88
Conductivity	µS/cm	286	n.a	n.a	381
Ca <sup>2+</sup>	mg/L	45.00	42.00	9.00	6.43
	meq/L	2.25	2.1	0.45	0.32
Na <sup>+</sup>	mg/L	17.00	27.00	4.00	68.19
	meq/L	0.74	1.17	0.17	2.96
Mg <sup>2+</sup>	mg/L	4.00	2.00	2.00	3.02
	meq/L	0.33	0.17	0.17	0.25
K <sup>+</sup>	mg/L	1.00	2.00	2.00	3.20
	meq/L	0.03	0.05	0.05	0.08
HCO <sub>3</sub> <sup>-</sup>	mg/L	241.00	286.00	61.00	820.5
	meq/L	3.95	4.69	0.99	13.45
SO <sub>4</sub> <sup>2-</sup>	mg/L	5.00	0.00	0.00	1.2
	meq/L	0.10	0.00	0.00	0.03
Cl <sup>-</sup>	mg/L	2.00	2.00	10.00	0.24
	meq/L	0.06	0.06	0.29	0.01
NO <sub>3</sub>	mg/L	n.a	n.a	n.a	n.a
	meq/L	n.a	n.a	n.a	n.a
Hardness as CaCO <sub>3</sub>	mg/L	128.90	113.20	30.70	28.46
Calculated TDS	mg/L	185.90	-	-	215.00
Total Cations	meq/L	3.35	3.49	0.84	3.61
Total Anions	meq/L	4.13	4.75	1.28	13.49
%Charge Balance		10.42	15.30	20.75	57.77

L 1<sup>a</sup> Bujang and Ramli (1998); L2<sup>a</sup> Tawnie and Bujang (2001); L 3<sup>a</sup> Bujang and Ramli (1998); L4<sup>a</sup> Groundwater Technology (2001)  
A<sup>b</sup> SRK Senibong; B<sup>b</sup> Kampung Simpang Bongkah; C<sup>b</sup> Kampung Sebandi Ulu; D<sup>b</sup> SK Stungkor

## **CHAPTER THREE**

### **MATERIALS AND METHODS**

#### **3.1 Materials**

The samples were collected from the groundwater well at the Sekolah Kebangsaan Stungkor along the Bau-Lundu road.

#### **3.2 Sampling Program**

The samples were collected once in a month beginning in September 2003 until February 2004. In each sampling, three samples each were taken at three different times i.e. morning, afternoon and evening.

#### **3.3 Sample Collection**

The samples were collected in a 1 or 2 liter containers. The containers were decontaminated by washing with detergent before sampling. The sampling bottles were pre-washed with a non-phosphate detergent such as Liquinox or its equivalent i.e. tap water rinsed and then washed in double deionised water. The samples were labeled (location, ID, date, time).

### 3.4 Sample Preservation

The samples were preserved so that the samples could be kept longer. A summary of acceptable EPA (U.S. Environmental Protection Agency, 1983) methods of preservation is shown in Table 4.

**Table 4 U.S. EPA Required Preservation Methods for Water (U.S. EPA, 1983)**

Test	Preservation Method	Maximum Recommended Holding Time
Conductivity	Store at 4°C	28 days
pH	Determine on site	No holding
Turbidity	Store at 4°C	48 days
Chloride	None Required	28 days
Nitrate	Store at 4°C	48 hours
Sulphate	Store at 4°C	28 days
Metals	Add H <sub>2</sub> SO <sub>4</sub> to pH<2, store at 4°C	6 months

### 3.5 Parameters Measured

The pH, electrical conductivity and turbidity measurements were made in the field. Carbonates and bicarbonate were determined by titration and the titration was done in the field. The analysis for the chemical species such as nitrate, sulphate, and chloride were performed by the DR/700 Colorimeter according to the specified methods. The samples were filtered and acidified to pH<2 with 2M H<sub>2</sub>SO<sub>4</sub> and then four cations which are calcium, sodium, magnesium and potassium were analyzed using the Perkin Elmer model 3110 Atomic Absorption Spectrometer (AAS).

## **CHAPTER FOUR**

### **RESULTS AND DISCUSSION**

#### **4.1 Results of the groundwater analysis**

The mean concentration of chemical constituents and other parameters is shown on Table

Table 5 Results of Groundwater Analyses

Parameter	S1	S2	S3	S4	S5	S6
pH	8.04	8.02	7.95	7.98	7.97	7.97
Turbidity	0.03	0.04	0.03	0.03	0.02	0.03
Conductivity	608	548	604	594	595	596
Ca <sup>2+</sup>	69.07	65.44	66.00	64.95	66.35	67.20
	3.45	3.27	3.30	3.25	3.32	3.36
Na <sup>+</sup>	28.93	28.34	29.08	26.25	28.54	25.48
	1.26	1.23	1.26	1.14	1.24	1.11
Mg <sup>2+</sup>	4.78	6.61	4.48	8.04	8.04	7.81
	0.40	0.55	0.37	0.66	0.66	0.64
K <sup>+</sup>	1.78	1.65	1.79	1.85	1.85	1.82
	0.05	0.04	0.05	0.05	0.05	0.05
CO <sub>3</sub> <sup>2-</sup>	-	-	-	-	-	-
	-	-	-	-	-	-
HCO <sub>3</sub> <sup>-</sup>	376.83	383.61	380.91	382.27	379.56	380.91
	6.17	6.28	6.24	6.26	6.22	6.24
SO <sub>4</sub> <sup>2-</sup>	13.22	13.78	13.56	13.78	13.38	13.89
	0.27	0.28	0.28	0.28	0.27	0.28
Cl <sup>-</sup>	10.00	10.00	10.00	10.00	10.00	10.00
	0.28	0.28	0.28	0.28	0.28	0.28
NO <sub>3</sub>	0.23	0.22	0.23	0.03	0.03	0.14
	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Hardness as CaCO <sub>3</sub>	192.27	190.70	183.39	195.34	198.84	200.02
Calculated TDS	395.20	356.20	392.60	386.10	386.75	387.40
Total Cations	5.16	5.09	4.98	5.10	5.27	5.16
Total Anions	6.95	7.06	7.03	6.85	6.80	6.94
% Charge Balance	14.78	16.21	17.06	14.64	12.67	14.71

<sup>a</sup> S1, S2, S3, S4, S5 and S6 denoted September, October, November, December, January and February respectively.

<sup>b</sup> all the values are the averages for each parameter

## 4.2 Charge Balance

The charge balance percentages of the studied groundwater are between 12.67% and 17.06% (see Table 5). Theoretically the sum of the anions balances the sum of the cations (Fetter, 1994). The charge balances from the other groundwater analyses of the “Kayang” Sandstone obtained from literature are given in Table 6 below. The charge balance results of this study are similar to those reported in literature.

**Table 6 Charge Balance Results from Analyses Reported in Literature.**

Analyses from Literature	L1 <sup>a</sup>	L2 <sup>a</sup>	L3 <sup>a</sup>	L4 <sup>a</sup>
	A <sup>b</sup>	B <sup>b</sup>	C <sup>b</sup>	D <sup>b</sup>
Charge Balance (%)	10.42	15.30	20.75	57.77
L 1 <sup>a</sup> Bujang and Ramli (1998); L2 <sup>a</sup> Tawnie and Bujang (2001); L 3 <sup>a</sup> Bujang and Ramli (1998); L4 <sup>a</sup> Groundwater Technology (2001) A <sup>b</sup> SRK Senibong; B <sup>b</sup> Kampung Simpang Bongkah; C <sup>b</sup> Kampung Sebandi Ulu; D <sup>b</sup> SK Stungkor				

This differences between the cations and anions are attributed is due to the analytical error or other constituents being present.

## 4.3 Comparison with Hydrogeochemical Data from the “Kayang” Sandstone from Literature.

A comparison of the groundwater investigated with other hydrogeochemical studies from the “Kayang” Sandstone was made. The hydrogeochemical analyses from literature and from investigations in this study are shown below indicated as L1–L4 and S1–S6 respectively.

### 4.3.1 Vertical Bar Diagrams for the Hydrogeochemical Analyses.

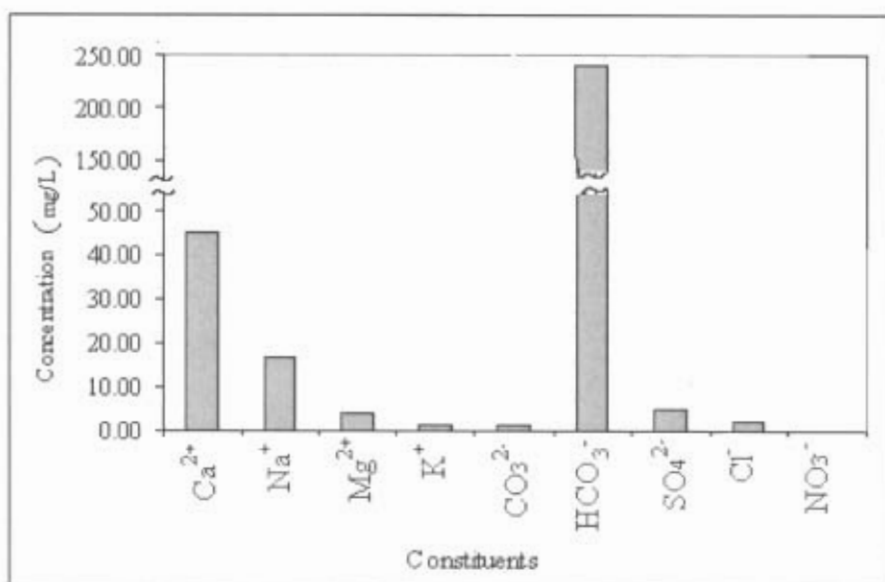


Figure 2 Analysis L1

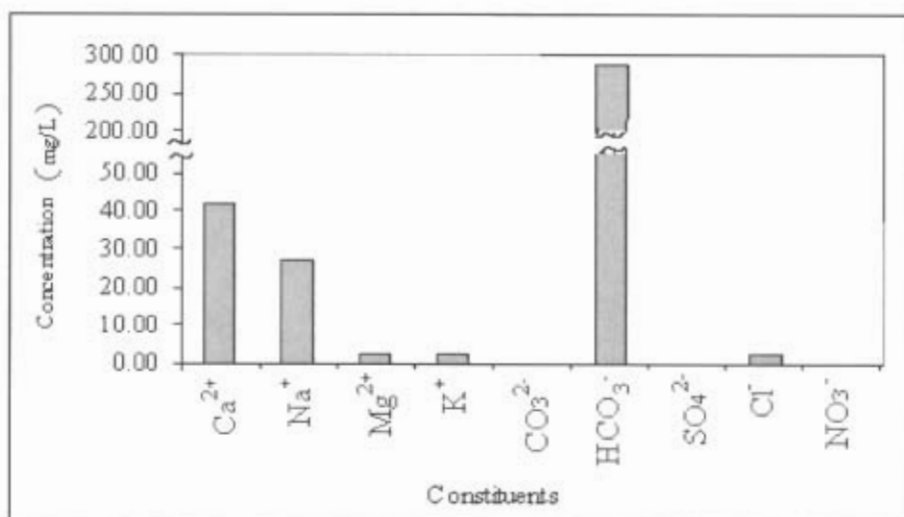


Figure 3 Analysis L2

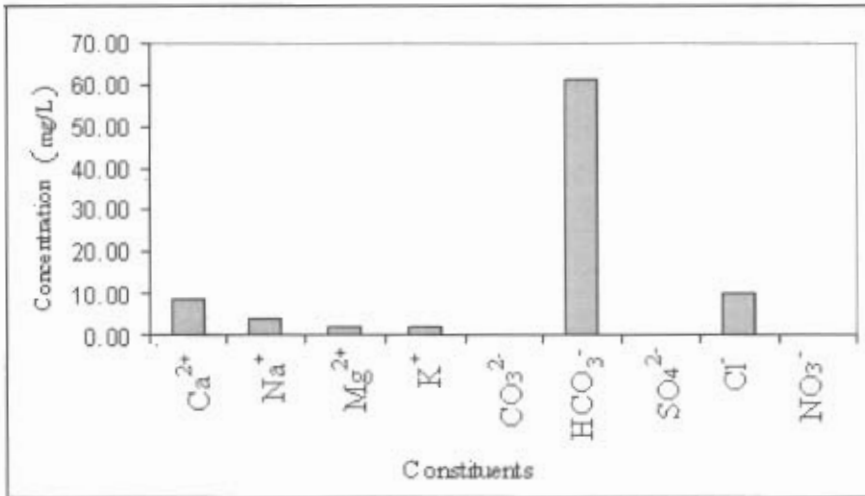


Figure 4 Analysis L3

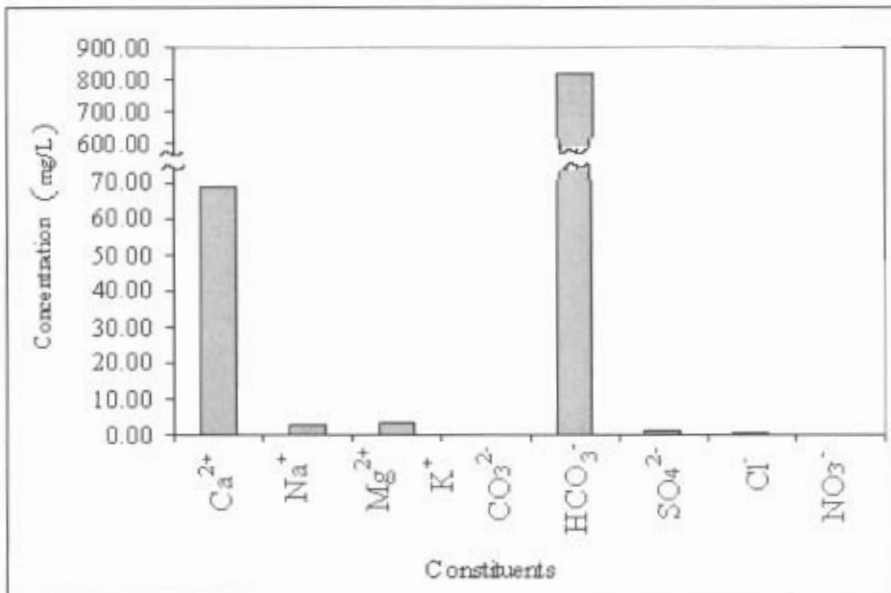


Figure 5 Analysis L4



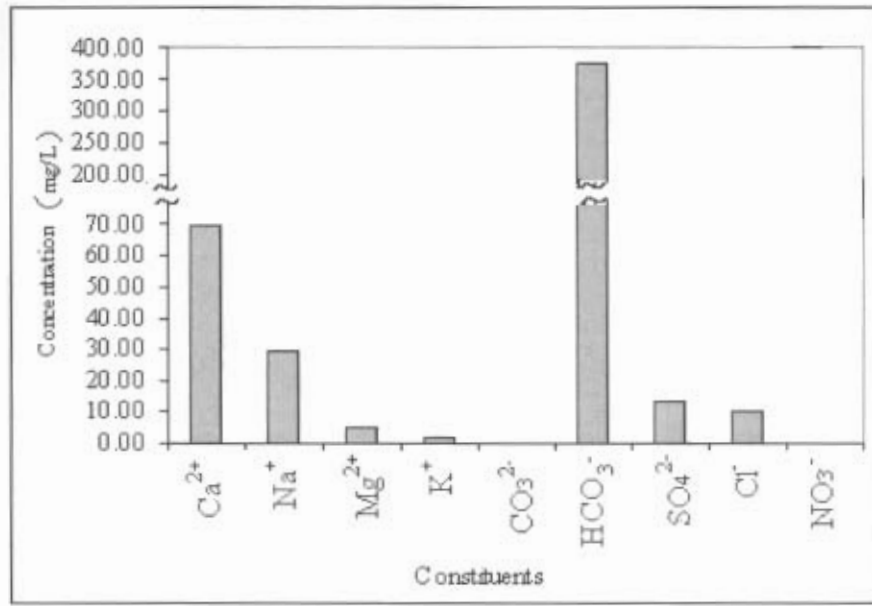


Figure 6 S1 (September)

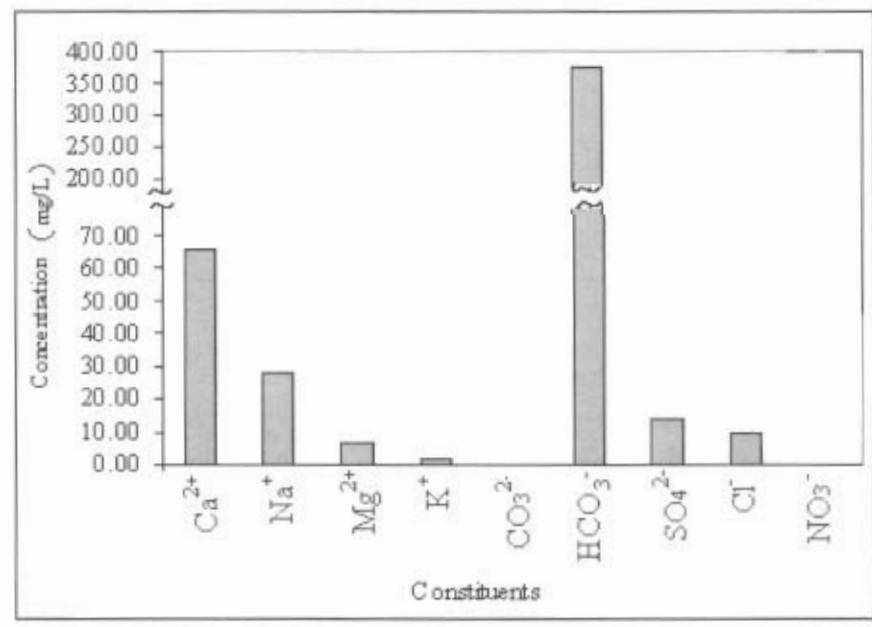


Figure 7 S2 (October)

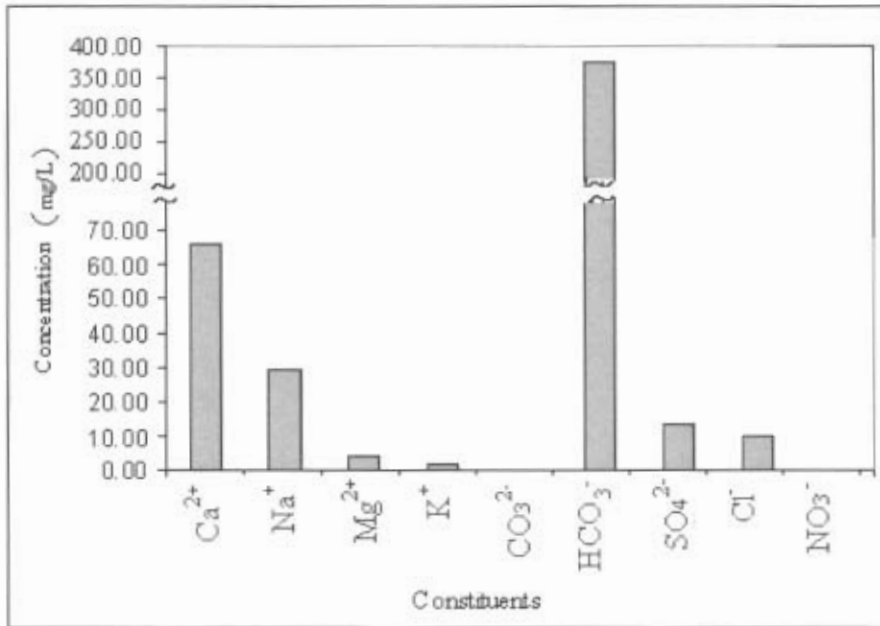


Figure 8 S3 (November)

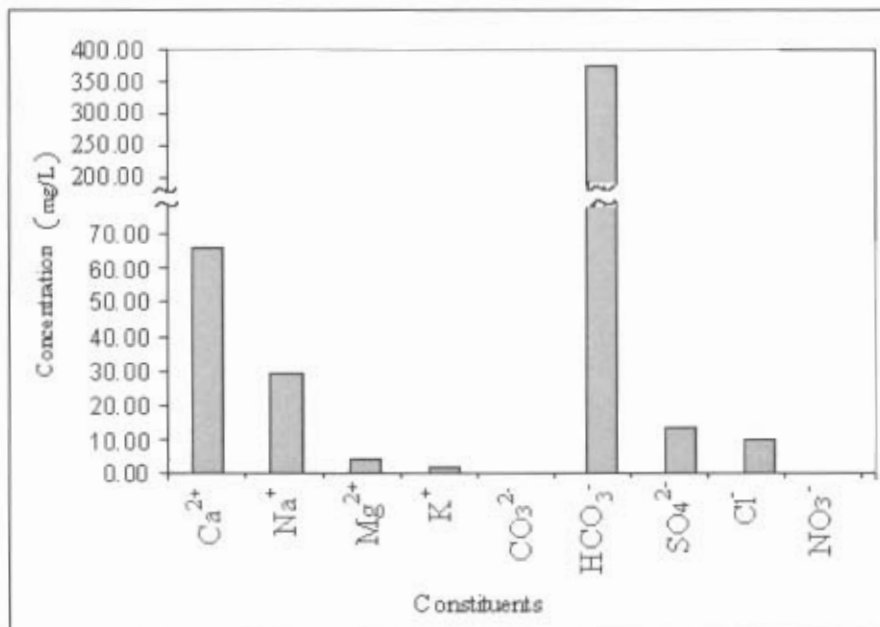


Figure 9 S4 (December)

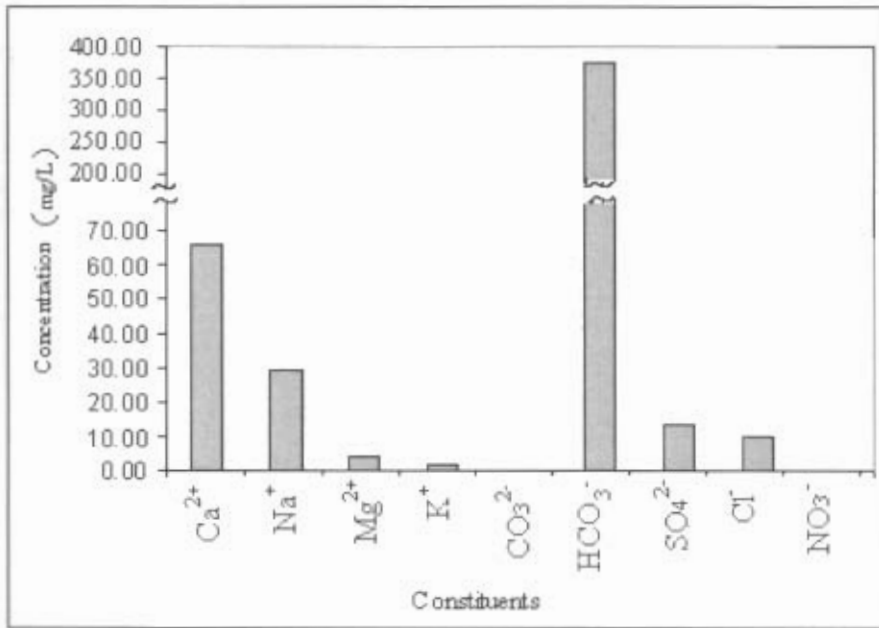


Figure 10 S5 (January)

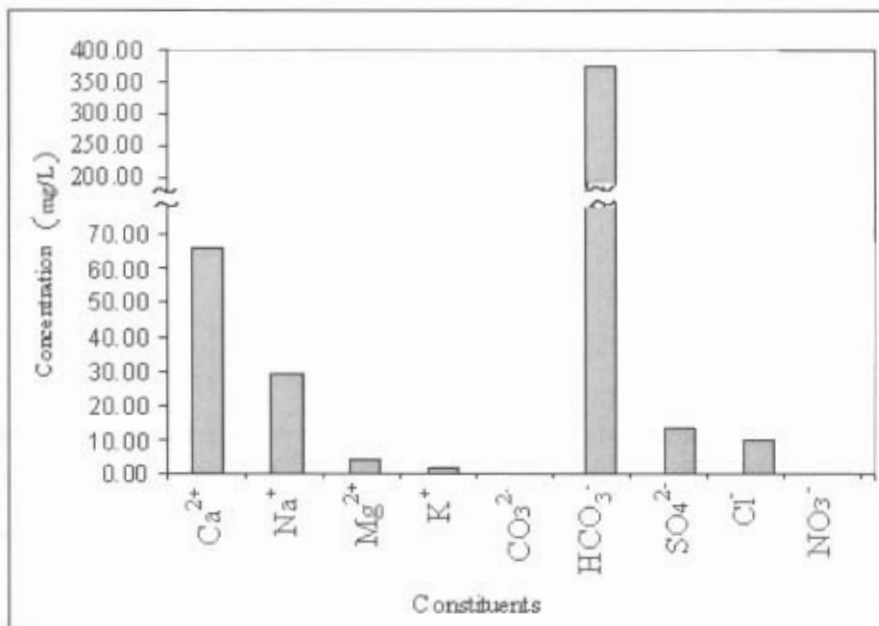


Figure 11 S6 (February)

The analyses presented in Figures 2 to 11 above show a similar trend for the different elements although the actual concentrations vary. The striking feature is that each of these analyses shows much higher HCO<sub>3</sub><sup>-</sup> concentrations.

### 4.3.2 Stiff Diagrams Representing the Hydrogeochemical Data.

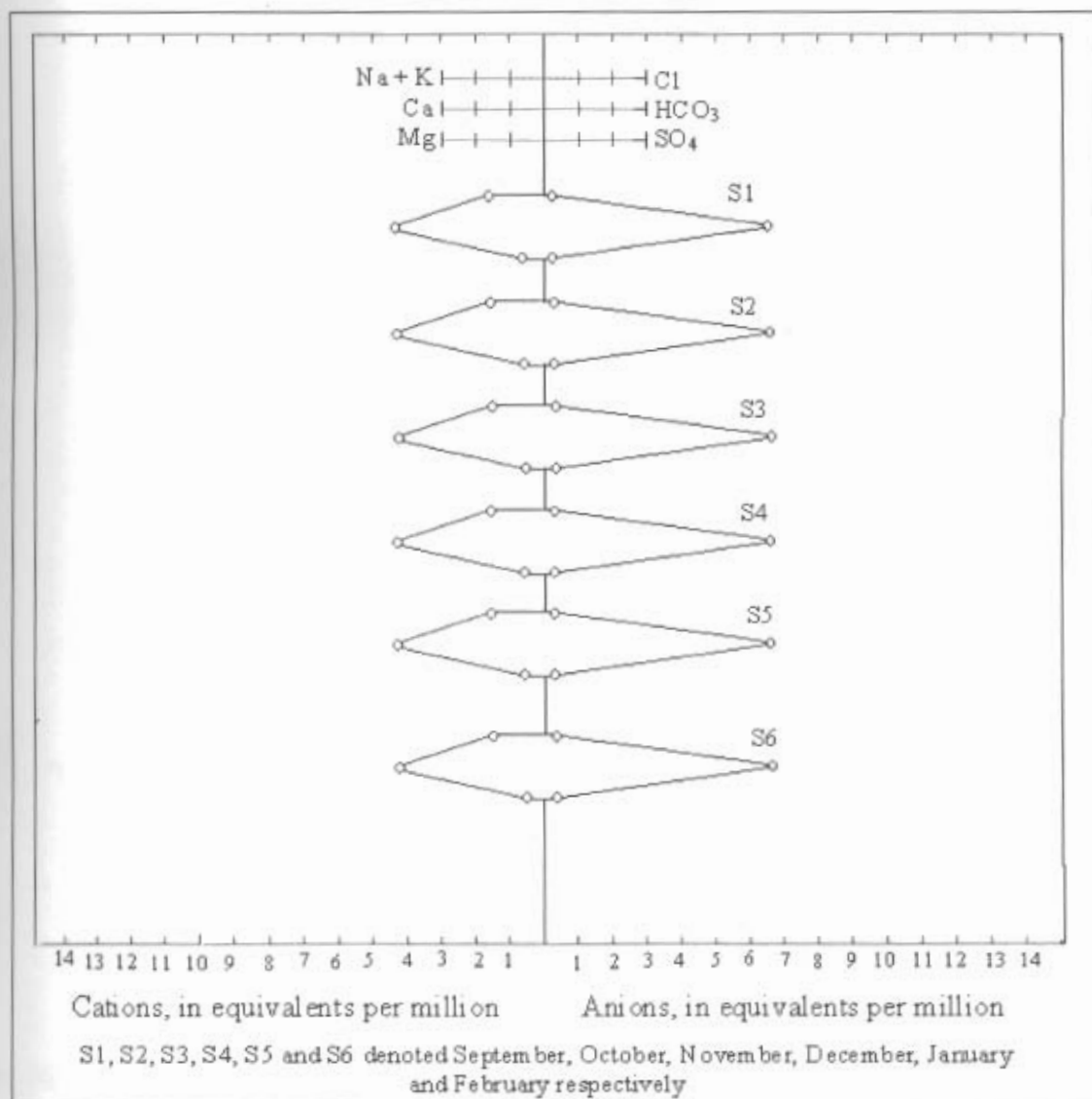
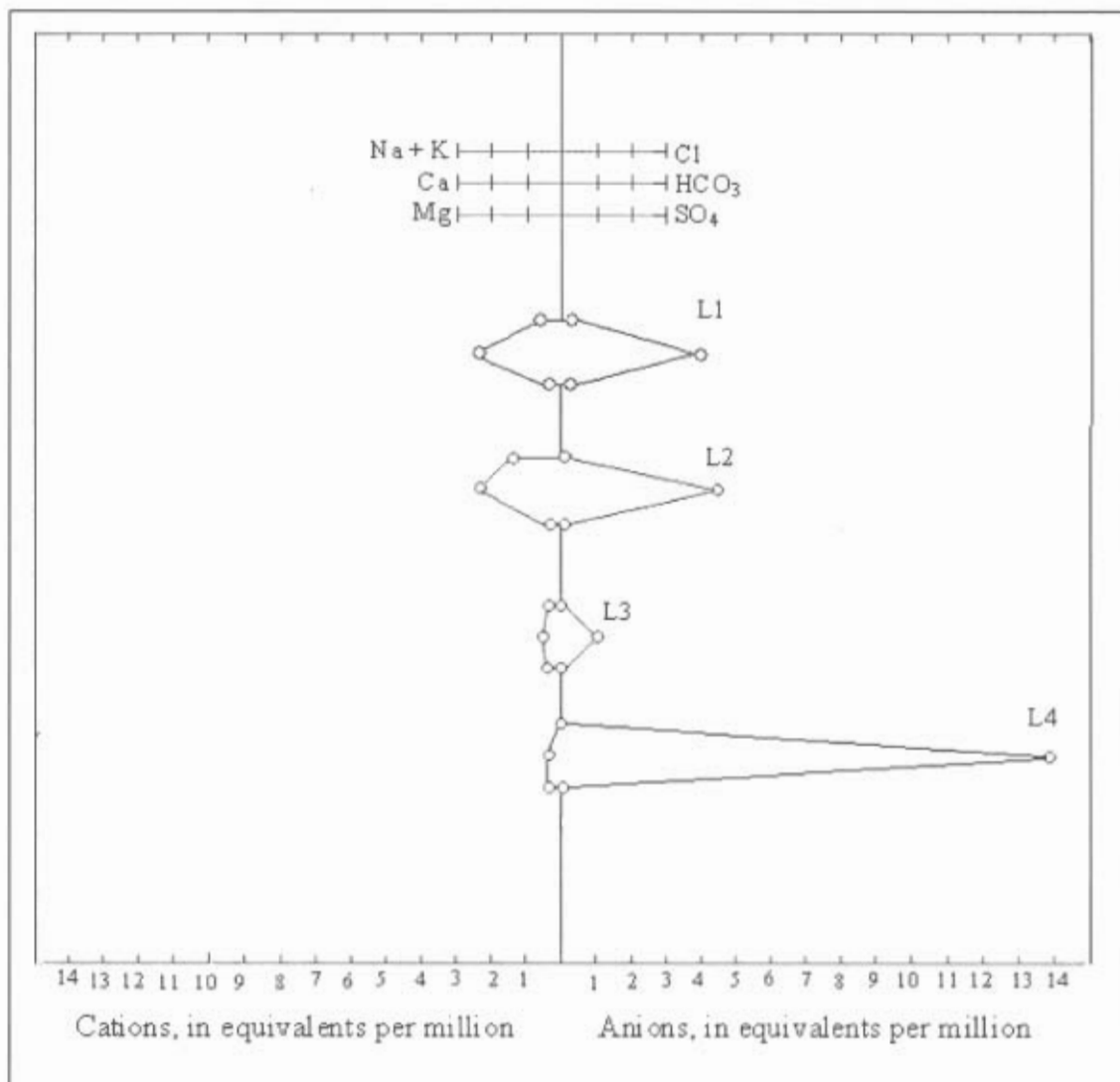


Figure 12 Stiff diagram for S1 – S6

The Stiff Diagram in Figure 12 indicates that the samples are alike with similar chemical concentrations as these do not change over time.

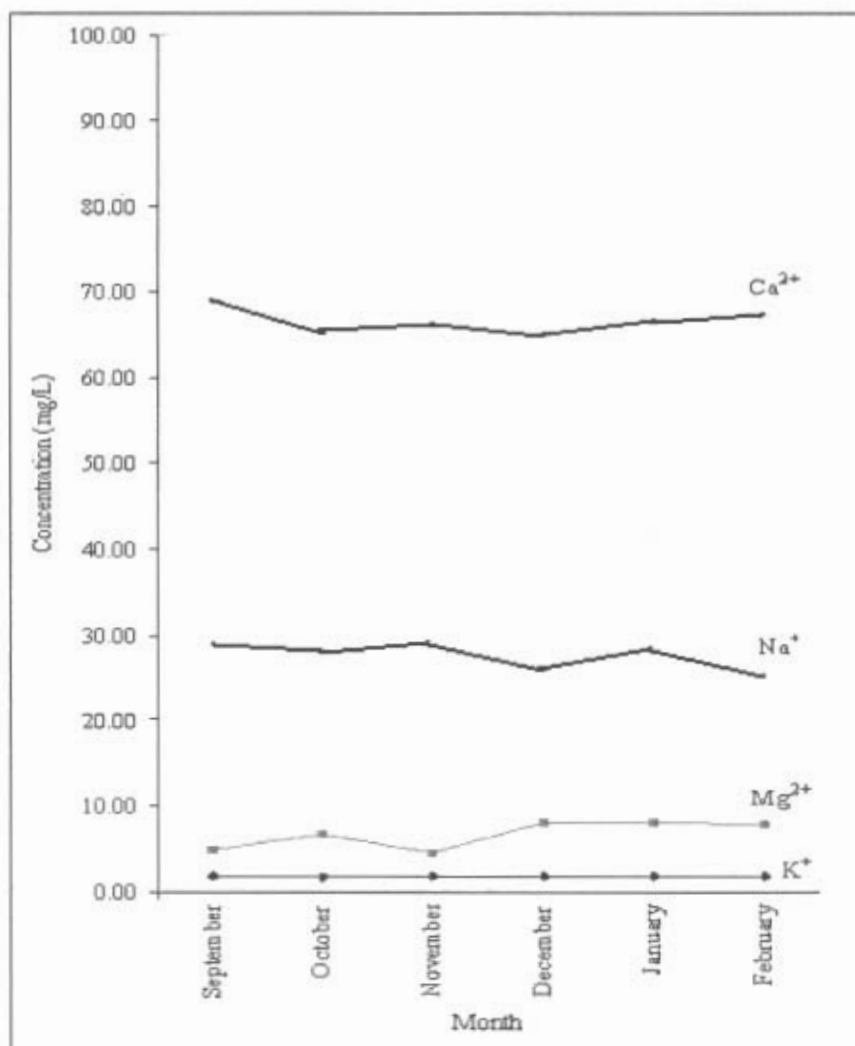


**Figure 13 Stiff diagram for L1 – L4**

The Stiff Diagram in Figure 13 indicates that the various samples are different as they have different concentrations of the respective cations and anions but again the samples display a similar trend with respect to the different cations and anions.

#### 4.4 Monthly Comparisons

The cations and anions concentrations were plotted for every month of sampling to view the concentration variation from month to month. These are shown in Figure 14 and Figure 15.



**Figure 14 Monthly groundwater cation concentrations**

The graphs show that the calcium concentration is the highest followed by sodium, magnesium and potassium. There was not much difference in each cation over the months except for magnesium which varied between 4.48 mg/L to 8.04 mg/L. There was a significant difference between the concentrations of the different cations in all the months. The concentrations of the other cations i.e. calcium, sodium and potassium were in a range between 64.95mg/L to 69.07 mg/L, 25.48 mg/L to 29.08 mg/L and 1.65 mg/L to 1.85 mg/L respectively.

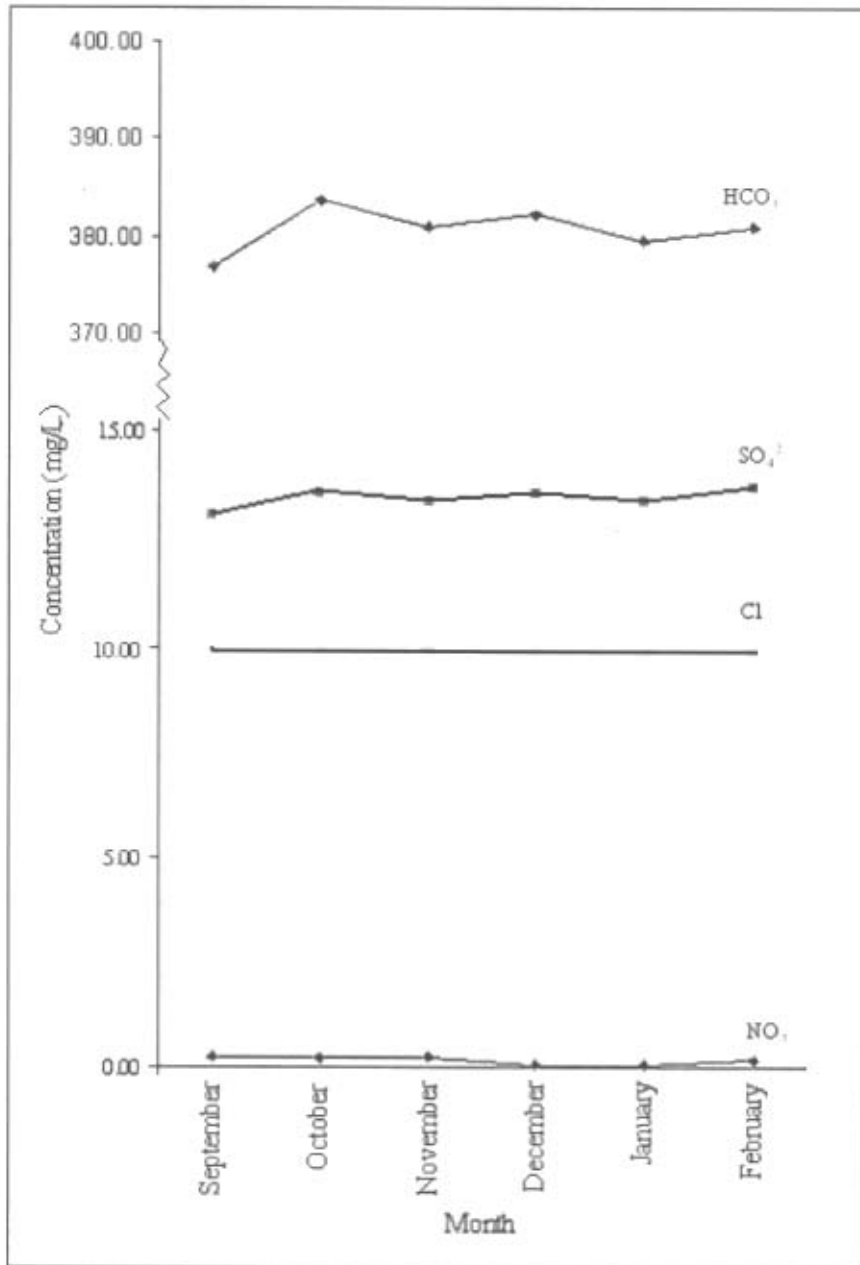


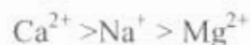
Figure 15 Monthly groundwater anion concentrations

As shown in Figure 3, the bicarbonate concentration was the highest with a range of 408.70 mg/L to 433.78 mg/L. The nitrate concentration was the lowest with values in the around 0.03 mg/L to 0.23 mg/L. The sulphate concentration did not vary as it lay around 13.22mg/L to 13.78 mg/L and the chloride concentration had a mean value of 10.00mg/L for all the months.

The concentrations of the major cations and anions in the groundwater investigated remained constant with time. This may be attributed to the slow movement of groundwater and its long residence time within the geologic formation (Todd, 1980). The equilibrium achieved by the various chemical reactions such as dissolution and precipitation, ion exchange, mixing, oxidation and reduction and membrane effects tends to produce a quality that remains stable with time (Mandel & Shiftan, 1981).

#### 4.5 Hydrochemical Facies of the Groundwater

The dominant cations and anions identify the geochemical group to which the water belongs (Mandel and Shiftan, 1981). By converting the concentration value from milligram per liter to milliequivalent per liter, the cations and anions can be ranked in order of decreasing magnitude and can be represent by an *ionic formula*. The *ionic formula* of the groundwater investigated can be represented as;

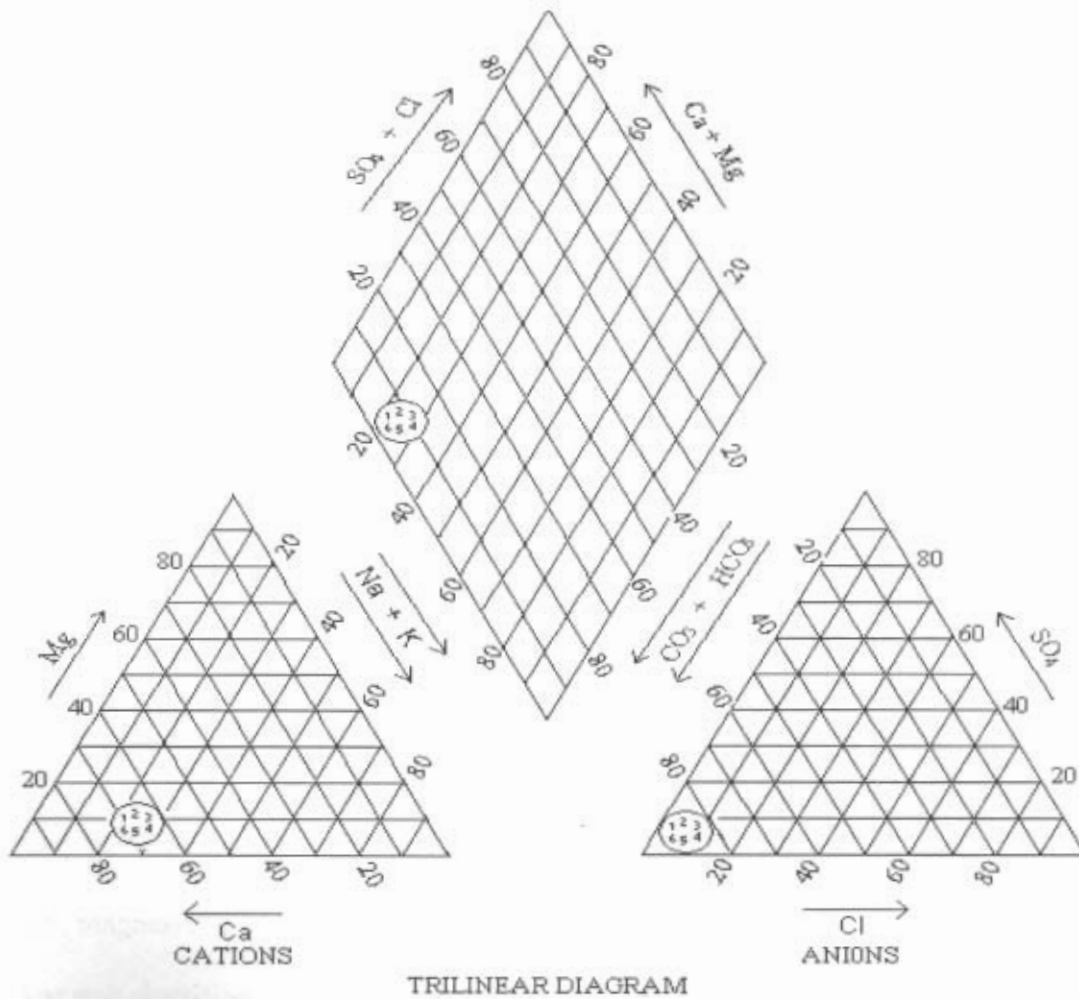


The Piper trilinear diagram is used to representation widely divergent water types (Mandel and Shiftan, 1981). This diagram comprises two triangular coordinates for cations and anions respectively and one rhomboid grid (diamond-shaped area). Concentrations are plotted as percentages of total cations or anions concentrations in milliequivalents. The two



points in the triangle then are projected into the rhomboid grid parallel to the upper edge of the central area. Their intersection is uniquely related to the total ionic distribution and a circle is drawn at this point with its area proportional to the total dissolved solids (TDS).

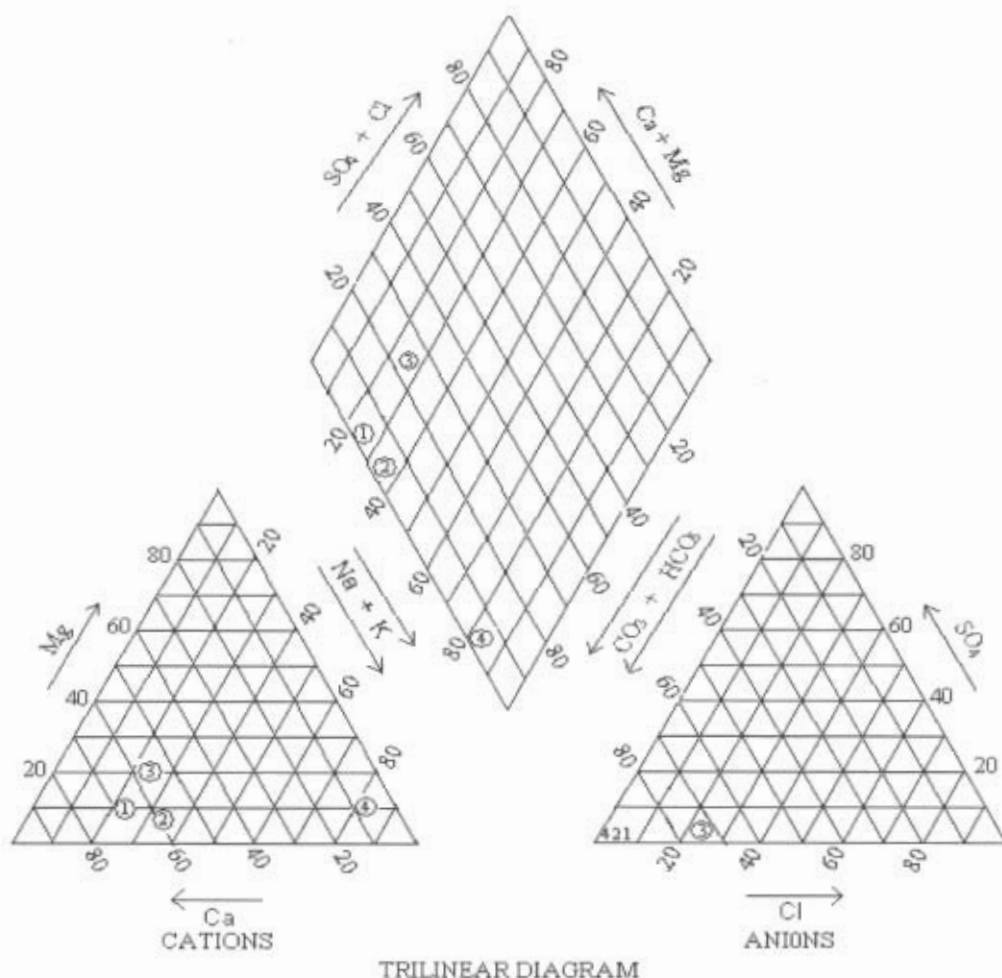
Upon the analytical data from the this investigation being plotted on the Piper trilinear diagram, shown in Figure 16, the groundwater can be classified as 'calcium bicarbonate' water.



**Figure 16** Classification of the groundwater water from in this investigation.

The analyses from this investigation i.e. groundwater from SK Stungkor and four analyses from literature were plotted on a Piper diagram. The Piper diagram shown as Figure 17,

indicated that all these samples were of an identical water type i.e 'calcium bicarbonate' water.



**Figure 17 Groundwater Classification of Selected Chemical Analysis from Kayan Sandstone Formation. The figures refer to analyses in Table 3.**

However, the analyses L3 of groundwater from Kampung Sebandi Ulu was classified as 'calcium, magnesium, sodium, bicarbonate' water and analyses L4 of groundwater from SK Stungkor was classified as 'sodium, bicarbonate' water.

#### 4.6 Hardness

Hardness results from the presence of divalent metallic cations, of which calcium and magnesium are the most abundant in groundwater (Todd, 1980). According to Bujang &

Ramli (1998) hardness of the water can be defined as the ability of water to react with soap to produce a sum residue and expressed as the total concentration of calcium and magnesium as equivalent  $\text{CaCO}_3$  in mg/L. Total hardness can be calculated by the Equation 1 (Todd, 1980).

$$H_T = 2.5\text{Ca} + 4.1\text{Mg} \quad (1)$$

The degree of hardness in water based on the classification listed in Table 4 (after Sawyer and McCarty, 1967)

**Table 7 Hardness Classification of Water (after Sawyer and McCarty, 1967)**

Hardness Range (mg/L $\text{CaCO}_3$ )	Description
0-75	Soft
75-150	Moderately hard
150-300	Hard
Over 300	Very hard

The values of calcium and magnesium were taken for calculation of total hardness of the water.

The total hardness of the studied groundwater ranged from 183.39 mg/L to 200.02mg/L and this value fell in the range of 150 to 300 mg/L  $\text{CaCO}_3$ . Therefore, this groundwater classified as hard water.

#### 4.7 Groundwater Quality

Water quality is expressed by classes of relative suitability of the purpose it is intended to be used (Todd, 1980). The quality classification of water for irrigation is shown in Table 8.

**Table 8 Quality Classification of Water for Irrigation (from Todd, 1980)**

Water Class	Percent Sodium	Specific Conductance, $\mu\text{S}/\text{cm}$
Excellent	<20	<250
Good	20-40	250-750
Permissible	40-60	750-2000
Doubtful	60-80	2000-3000
Unsuitable	>80	>3000

The percent sodium as an expression of the sodium content in the water is calculated by Equation 2 (Todd, 1980).

$$\% \text{ Na} = \left[ \frac{(\text{Na} + \text{K})}{(\text{Ca} + \text{Mg} + \text{Na} + \text{K})} \right] \times 100$$

(2)

where all ionic concentrations are expressed in milliequivalents per liter. By calculation, the percent sodium and specific conductance of the studied groundwater is in the range of 22-25% and 548-608  $\mu\text{S}/\text{cm}$  respectively. Based on classification of water in Table 5, the class of the studied groundwater falls within the good classification.

The most common contaminant identified in groundwater is dissolved nitrogen in the form of nitrate ( $\text{NO}_3^-$ ). This contaminant is mostly produced by agricultural activities and disposal of sewage on or under the land surface (Freeze and Cherry, 1979). Nitrate in groundwater generally originates from nitrate sources on the land surface, in the soil zone, or in shallow subsoil zones where nitrogen-rich wastes are buried. In some situations nitrate that enters the groundwater systems originates as nitrate in wastes or fertilizers applied to the land surface (Freeze and Cherry, 1979). A range of 0.03 mg/L to 0.23 mg/L of nitrate was observed in the studied groundwater for the six months of observation. The range of nitrate concentration is very low under the recommended limit of 10mg/L (Todd, 1980).

## CHAPTER FIVE

### CONCLUSION

The concentrations of the major cations and anions in the groundwater studied remain constant stable over six months of investigation.

From the Piper plot, the groundwater studied from the groundwater well at Sekolah Kebangsaan Stungkor can be classified as 'calcium bicarbonate' water. The groundwater was identical with the groundwater from Sekolah Rendah Kebangsaan Senibong and Kampung Simpang Bokah lying within the same aquifer.

The groundwater quality is generally good. The water has an average chloride content of 10.00mg/L. The other chemical constituents such as Ca, Mg, Na, K,  $\text{HCO}_3$ ,  $\text{SO}_4$  are well below the W.H.O. Standard for drinking water. Total hardness of the groundwater studied ranged from 183.39 mg/L to 200.02mg/L and the values fall in the range of 150 to 300 mg/L . The  $\text{CaCO}_3$  classified this groundwater as hard water. To make this water most suitable for domestic use, further treatment is needed to reduce the concentration of calcium and magnesium.

The percent sodium and specific conductance of 22-25% and 548-608  $\mu\text{S}/\text{cm}$  respectively makes this groundwater good for irrigation purpose. However, the other limit for the irrigation purpose such as the boron concentration should be considered. (Boron is necessary in very small quantities for normal growth of all plants, but in larger concentrations it becomes toxic [Todd, 1980]).

The nitrate concentration is considered for detecting pollution in the groundwater. The range of nitrate concentration is very low under the recommended limit of 10mg/L (Todd, 1980). It was found that the groundwater is not polluted by the nitrate sources such as wastes or fertilizers applied to the land surface.

## REFERENCES

- Bailey, P.E. and Ward, W.D. (1990). *Understanding Groundwater Contamination: An Orientation Manual*. Executive Enterprise, New York, pp. 205
- Bowen, R. (1986). *Groundwater*, Elsevier, London, pp.3
- Bujang, Y. and Ramli, M.Z.(1998). *Report on Hydrogeological Investigation at SRK Senibong, Lundu District, Kuching Division, Sarawak*. Department of Minerals and Geosains, Sarawak.
- Bujang, Y. and Ramli, M.Z.(1998). *Report on Hydrogeological Investigation at Kampung Sebandi Ulu, Lundu District, Kuching Division, Sarawak*. Department of Minerals and Geosains, Sarawak.
- Bujang, Y. and Tawnie, I. (2001). *Report on Hydrogeological Investigation at Kampung Simpang Bokah, Lundu District, Kuching Division, Sarawak*. Department of Minerals and Geosains, Sarawak
- Department of Environment, Malaysia [DoE] (2002). *Final Report, Development of Groundwater Quality Monitoring Network in Sarawak*, Center for Technology Transfer and Consultancy, University Malaysia Sarawak.
- Fetter, C.W. (1994). *Applied Hydrology*. Macmillan, New York, pp.423
- Freeze, R.A. and Cheery, J.A.(1979). *Groundwater*. Prentice-Hall, New Jersey, pp. 238-302
- Herzog, B.L., Pennino, J.D. and Nielsen, G.L. (1991). *Practical Handbook of Groundwater Monitoring*. Lewis Publishers, Michigan, pp. 185-230
- Mandel, S. and Shiftan, Z.L. (1981). *Groundwater Resources: Investigation and Development*. Academic Press, London, pp. 180-201
- Price, M. (1996). *Introducing Groundwater*. Chapman and Hall, London, pp. 172-225

- Sawyer, C.N. and McCarty, P.L.(1967). *Chemistry for Sanitary Engineers*. 2<sup>nd</sup> ed., McGraw-Hill, New York, pp. 518
- Tan, D.N.K. (1993). *Geology of the Kuching Area, West Sarawak, Malaysia*. Geological Survey of Malaysia, Sarawak, pp.72-84
- Todd, D.K.(1980). *Groundwater Hydrology*. John Wiley and Sons, Toronto, pp. 267-313
- U.S. Environmental Protection Agency (1983). *Quality Criteria for Water*. Washington, D.C., pp.501
- Wolfenden, E.B. (1963). *Sematan and Lundu area, West Sarawak, Report 1*. Geological Survey of Malaysia, Sarawak.
- White, D.E., *et al.* (1963). Data of Geochemistry- Chemical Composition of Subsurface Waters. 6<sup>th</sup> ed., U.S. Geological Survey Prof. Paper 440-F, pp. 67



**APPENDIX A**  
**EXPERIMENTAL DATA**

## APPENDIX A I Experimental Data for Groundwater Analysis on September

	Sample Number	RIA1	RIA2	RIA3	RIA ±SD	R1B1	R1B2	R1B3	R1B ±SD	R1C1	R1C2	R1C3	R1C ±SD
Parameter	Time	1100				1330				1500			
Ca <sup>2+</sup>	mg/L	69.23	69.56	69.82	69.54 ±0.29	69.05	68.98	68.75	68.93 ±0.15	68.88	69.00	68.75	68.88 ±0.12
Na <sup>+</sup>	mg/L	28.56	29.02	28.85	28.81 ±0.23	28.69	29.25	28.94	28.96 ±0.28	29.00	29.63	28.45	29.03 ±0.59
Mg <sup>2+</sup>	mg/L	5.02	4.83	5.10	4.98 ±0.13	4.57	4.60	4.60	4.59 ±0.02	4.74	4.80	4.80	4.78 ±0.03
K <sup>+</sup>	mg/L	1.75	1.78	1.78	1.77 ±0.02	1.81	1.79	1.81	1.80 ±0.01	1.78	1.78	1.75	1.77 ±0.02
CO <sub>3</sub> <sup>2-</sup>	mg/L	-	-	-	-	-	-	-	-	-	-	-	-
HCO <sub>3</sub> <sup>-</sup>	mg/L	372.10	378.20	384.20	378.17 ±6.05	378.20	378.20	372.10	376.17 ±3.52	384.20	378.20	378.20	380.20 ±3.46
Cl <sup>-</sup>	mg/L	10.00	10.00	10.00	10.00 ±0.00	10.00	10.00	10.00	10.00 ±0.00	10.00	10.00	10.00	10.00 ±0.00
SO <sub>4</sub> <sup>2-</sup>	mg/L	13.00	14.00	13.00	13.33 ±0.55	14.00	14.00	13.00	13.67 ±0.57	12.00	13.00	13.00	12.67 ±0.57
NO <sub>3</sub> <sup>-</sup>	mg/L	0.22	0.26	0.22	0.23 ±0.02	0.18	0.26	0.26	0.23 ±0.04	0.22	0.26	0.22	0.23 ±0.02
pH		8.08	8.10	8.09	8.09 ±0.01	8.08	8.08	8.09	8.08 ±0.01	8.00	8.01	8.00	8.00 ±0.01
Turbidity	NTU	0.03	0.02	0.02	0.02 ±0.01	0.03	0.03	0.03	0.03 ±0.00	0.02	0.03	0.03	0.03 ±0.01
Conductivity	µS	617	606	625	616 ±9	611	605	602	606 ±5	600	601	602	601 ±1
Temperature	°C	28.1	28.2	28.2	28.2 ±0.1	27.5	27.8	27.6	27.6 ±0.2	27.5	27.5	27.7	27.6 ±0.1

**APPENDIX A II Experimental Data for Groundwater Analysis on October**

	Sample Number	R2A1	R2A2	R2A3	R2A ±SD	R2B1	R2B2	R2B3	R2B ±SD	R2C1	R2C2	R2C3	R2C ±SD
Parameter	Time	950				1150				1350			
Ca <sup>2+</sup>	mg/L	65.20	66.14	66.25	65.86 ±0.57	65.12	64.80	65.12	65.01 ±0.18	65.30	66.00	64.99	65.43 ±0.52
Na <sup>+</sup>	mg/L	28.49	28.57	28.27	28.44 ±0.15	28.34	28.44	28.40	28.39 ±0.05	27.98	28.20	28.35	28.18 ±0.18
Mg <sup>2+</sup>	mg/L	6.61	6.62	6.62	6.62 ±0.01	6.60	6.66	6.61	6.62 ±0.03	6.60	6.58	6.62	6.60 ±0.02
K <sup>+</sup>	mg/L	1.68	1.68	1.65	1.67 ±0.01	1.66	1.67	1.65	1.66 ±0.01	1.64	1.60	1.64	1.63 ±0.02
CO <sub>3</sub> <sup>2-</sup>	mg/L	-	-	-	-	-	-	-	-	-	-	-	-
HCO <sub>3</sub> <sup>-</sup>	mg/L	390.40	390.40	384.30	388.37 ±3.52	384.30	378.20	390.40	384.30 ±6.10	372.10	378.20	384.20	378.17 ±6.05
Cl <sup>-</sup>	mg/L	10.00	10.00	10.00	10.00 ±0.00	10.00	10.00	10.00	10.00 ±0.00	10.00	10.00	10.00	10.00 ±0.00
SO <sub>4</sub> <sup>2-</sup>	mg/L	14.00	14.00	13.00	13.67 ±0.57	13.00	14.00	14.00	13.67 ±0.57	14.00	14.00	14.00	14.00 ±0.00
NO <sub>3</sub> <sup>-</sup>	mg/L	0.20	0.26	0.22	0.23 ±0.03	0.20	0.18	0.22	0.20 ±0.02	0.22	0.24	0.23	0.23 ±0.01
pH		8.00	8.00	8.02	8.01 ±0.01	7.97	8.02	8.01	8.00 ±0.02	8.04	8.05	8.05	8.05 ±0.01
Turbidity	NTU	0.04	0.04	0.04	0.04 ±0.00	0.03	0.04	0.04	0.04 ±0.01	0.04	0.04	0.04	0.04 ±0.00
Conductivity	µS	558	542	543	548 ±8	540	541	541	541 ±1	559	550	554	554 ±5
Temperature	°C	30.4	30.2	30.4	30.3 ±0.1	30.1	29.6	29.4	29.7 ±0.3	29.2	28.7	28.5	28.8 ±0.3

**APPENDIX A III Experimental Data for Groundwater Analysis on November**

	Sample Number	R3A1	R3A2	R3A3	R3A ±SD	R3B1	R3B2	R3B3	R3B ±SD	R3C1	R3C2	R3C3	R3C ±SD
Parameter	Time	1030				1230				1400			
Ca <sup>2+</sup>	mg/L	66.94	66.56	65.92	66.47 ±0.52	66.12	66.11	66.24	66.16 ±0.07	65.45	65.26	65.38	65.36 ±0.10
Na <sup>+</sup>	mg/L	29.53	30.12	29.15	29.60 ±0.48	29.15	28.90	29.10	29.05 ±0.13	28.90	28.90	28.00	28.60 ±0.51
Mg <sup>2+</sup>	mg/L	4.59	4.59	4.61	4.60 ±0.01	4.37	4.45	4.39	4.40 ±0.04	4.50	4.46	4.39	4.45 ±0.05
K <sup>+</sup>	mg/L	1.75	1.78	1.82	1.78 ±0.03	1.79	1.78	1.79	1.79 ±0.01	1.82	1.81	1.81	1.81 ±0.01
CO <sub>3</sub> <sup>2-</sup>	mg/L	-	-	-	-	-	-	-	-	-	-	-	-
HCO <sub>3</sub> <sup>-</sup>	mg/L	372.10	384.30	378.20	378.20 ±6.10	384.30	390.40	372.10	382.27 ±9.32	390.40	396.50	384.30	390.40 ±6.10
Cl <sup>-</sup>	mg/L	10.00	10.00	10.00	10.00 ±0.00	10.00	10.00	10.00	10.00 ±0.00	10.00	10.00	10.00	10.00 ±0.00
SO <sub>4</sub> <sup>2-</sup>	mg/L	14.00	14.00	13.00	13.67 ±0.57	14.00	14.00	13.00	13.67 ±0.57	14.00	13.00	13.00	13.33 ±0.57
NO <sub>3</sub> <sup>-</sup>	mg/L	0.26	0.22	0.22	0.23 ±0.02	0.22	0.26	0.26	0.25 ±0.02	0.22	0.22	0.22	0.22 ±0.00
pH		7.94	7.94	7.93	7.94 ±0.01	7.97	7.95	7.95	7.96 ±0.01	7.95	7.96	7.94	7.95 ±0.01
Turbidity	NTU	0.03	0.03	0.03	0.03 ±0.00	0.03	0.03	0.02	0.03 ±0.01	0.03	0.03	0.02	0.03 ±0.01
Conductivity	µS	602	600	600	601 ±1	601	608	602	604 ±4	605	608	610	608 ±3
Temperature	°C	27.8	27.6	27.8	27.7 ±0.1	27.7	27.7	27.7	27.7 ±0.0	27.3	27.3	27.2	27.3 ±0.01

**APPENDIX A IV Experimental Data for Groundwater Analysis on December**

	Sample Number	R4A1	R4A2	R4A3	R4A ±SD	R4B1	R4B2	R4B3	R4B ±SD	R4C1	R4C2	R4C3	R4C ±SD
Parameter	Time	900				1100				1300			
Ca <sup>2+</sup>	mg/L	64.56	65.25	64.23	64.68 ±0.52	65.66	65.89	65.41	65.65 ±0.24	64.85	64.52	64.20	64.52 ±0.32
Na <sup>+</sup>	mg/L	26.13	26.10	26.15	26.13 ±0.02	26.22	26.33	26.55	26.37 ±0.16	26.55	26.51	26.85	26.54 ±0.18
Mg <sup>2+</sup>	mg/L	8.01	8.05	8.04	8.03 ±0.02	8.05	8.04	8.01	8.03 ±0.02	8.05	8.03	8.06	8.05 ±0.01
K <sup>+</sup>	mg/L	1.77	1.88	1.88	1.84 ±0.06	1.80	1.87	1.88	1.85 ±0.04	1.85	1.86	1.86	1.86 ±0.01
CO <sub>3</sub> <sup>2-</sup>	mg/L	-	-	-	-	-	-	-	-	-	-	-	-
HCO <sub>3</sub> <sup>-</sup>	mg/L	372.10	378.20	378.20	376.17 ±3.52	378.20	384.30	390.40	384.30 ±6.10	384.30	384.30	390.40	386.3 ±3.52
Cl <sup>-</sup>	mg/L	10.00	10.00	10.00	10.00 ±0.00	10.00	10.00	10.00	10.00 ±0.00	10.00	10.00	10.00	10.00 ±0.00
SO <sub>4</sub> <sup>2-</sup>	mg/L	15.00	14.00	14.00	14.33 ±0.57	14.00	14.00	14.00	14.00 ±0.00	14.00	13.00	12.00	13.00 ±1.00
NO <sub>3</sub> <sup>-</sup>	mg/L	0.04	0.06	0.04	0.05 ±0.01	0.02	0.02	0.03	0.02 ±0.01	0.02	0.04	0.03	0.03 ±0.01
pH		7.96	7.97	7.97	7.97 ±0.01	8.02	8.02	8.03	8.02 ±0.01	7.94	7.94	7.93	7.94 ±0.01
Turbidity	NTU	0.03	0.04	0.04	0.04 ±0.01	0.02	0.03	0.02	0.02 ±0.01	0.02	0.02	0.02	0.02 ±0.00
Conductivity	µS	597	588	587	591 ±6	599	594	596	596 ±3	596	596	590	594 ±4
Temperature	°C	26.0	26.5	26.9	26.5 ±0.5	27.2	27.3	27.5	27.3 ±0.2	27.8	28.5	28.0	28.1 ±0.4

**APPENDIX A V Experimental Data for Groundwater Analysis on January**

	Sample Number	R5A1	R5A2	R5A3	R5A ± SD	R5B1	R5B2	R5B3	R5B ±SD	R5C1	R5C2	R5C3	R5C ±SD
Parameter	Time		1000				1230				1400		
Ca <sup>2+</sup>	mg/L	67.25	67.97	66.98	67.40 ±0.51	65.33	64.25	65.22	64.93 ±0.59	67.45	65.66	67.00	66.70 ±0.93
Na <sup>+</sup>	mg/L	28.31	29.33	28.98	28.87 ±0.51	27.85	28.50	28.12	28.16 ±0.32	29.23	28.56	27.98	28.59 ±0.62
Mg <sup>2+</sup>	mg/L	4.75	4.73	4.76	4.75 ±0.01	4.71	4.75	4.69	4.72 ±0.03	4.84	4.88	4.80	4.84 ±0.04
K <sup>+</sup>	mg/L	1.87	1.88	1.88	1.88 ±0.01	1.76	1.75	1.73	1.75 ±0.02	1.83	1.84	1.84	1.84 ±0.01
CO <sub>3</sub> <sup>2-</sup>	mg/L	-	-	-	-	-	-	-	-	-	-	-	-
HCO <sub>3</sub> <sup>-</sup>	mg/L	372.10	378.20	378.20	376.17 ± 3.52	378.20	372.10	378.20	376.17 ±3.52	390.40	384.30	384.30	386.3 ±3.5 2
Cl <sup>-</sup>	mg/L	10.00	10.00	10.00	10.00 ±0.00	10.00	10.00	10.00	10.00 ±0.00	10.00	10.00	10.00	10.00 ±0.00
SO <sub>4</sub> <sup>2-</sup>	mg/L	15.00	14.00	13.00	14.00 ±1.00	14.00	13.00	14.00	13.67 ±0.57	13.00	14.00	13.00	13.33 ±0.57
NO <sub>3</sub> <sup>-</sup>	mg/L	0.18	0.26	0.13	0.19 ±0.06	0.22	0.22	0.22	0.22 ±0.00	0.26	0.26	0.26	0.26 ±0.00
pH		7.95	7.99	8.00	7.98 ±0.02	8.02	8.00	8.01	8.01 ±0.01	7.98	8.01	7.98	7.99 ±0.01
Turbidity	NTU	0.03	0.04	0.04	0.04 ±0.01	0.05	0.04	0.04	0.04 ±0.01	0.03	0.03	0.03	0.03 ±0.00
Conductivity	µS	604	605	603	604 ±1	606	600	603	603 ±3	607	600	603	603 ±4
Temperature	°C	28.3	28.6	28.4	28.4 ±0.2	28.4	29.0	29.3	28.9 ±0.4	29.1	29.2	29.2	29.2 ±0.1

**APPENDIX A VI Experimental Data for Groundwater Analysis on February.**

	Sample Number	R6A1	R6A2	R6A3	R6A ± SD	R6B1	R6B2	R6B3	R6B ±SD	R6C1	R6C2	R6B3	R6C ±SD
Parameter	Time		900				1100				1300		
Ca <sup>2+</sup>	mg/L	68.02	67.65	68.35	68.01 ±0.35	64.50	68.50	68.90	67.30 ±2.43	67.50	64.50	66.89	66.30 ±1.58
Na <sup>+</sup>	mg/L	25.56	26.55	25.29	25.850 ±0.66	25.20	26.10	25.78	25.69 ±0.45	25.65	25.21	24.00	24.95 ±0.85
Mg <sup>2+</sup>	mg/L	7.79	7.81	7.83	7.81 ±0.02	7.81	7.79	7.82	7.81 ±0.01	7.81	7.78	7.85	7.81 ±0.03
K <sup>+</sup>	mg/L	1.75	1.74	1.80	1.76 ±0.03	1.85	1.86	1.85	1.85 ±0.01	1.84	1.83	1.82	1.83 ±0.01
CO <sub>3</sub> <sup>2-</sup>	mg/L	-	-	-	-	-	-	-	-	-	-	-	-
HCO <sub>3</sub> <sup>-</sup>	mg/L	384.30	378.20	378.20	380.23 ±3.52	384.30	390.40	378.20	384.30 ±6.10	384.30	372.10	378.20	378.20 ±6.10
Cl <sup>-</sup>	mg/L	10.00	10.00	10.00	10.00 ±0.00	10.00	10.00	10.00	10.00 ±0.00	10.00	10.00	10.00	10.00 ±0.00
SO <sub>4</sub> <sup>2-</sup>	mg/L	14.00	14.00	13.00	13.67 ±0.57	14.00	15.00	14.00	14.33 ±0.57	14.00	14.00	13.00	13.67 ±0.57
NO <sub>3</sub> <sup>-</sup>	mg/L	0.12	0.14	0.13	0.13 ±0.01	0.15	0.16	0.15	0.15 ±0.01	0.15	0.14	0.14	0.14 ±0.01
pH		7.99	7.89	7.89	7.92 ±0.05	8.00	7.94	7.99	7.98 ±0.03	8.02	8.01	7.99	8.01 ±0.01
Turbidity	NTU	0.02	0.04	0.03	0.03 ±0.01	0.04	0.03	0.04	0.04 ±0.01	0.03	0.04	0.03	0.03 ±0.01
Conductivity	µS	599	590	592	594 ±5	598	590	600	596 ±5	599	600	598	599 ±1
Temperature	°C	28.0	29.0	28.5	28.5 ±0.5	28.0	29.0	28.0	28.3 ±0.5	29.0	29.3	29.2	29.2 ±0.2

**APPENDIX A VII Summary of groundwater analysis.**

Parameter	Sample Number	R1A	R1B	R1C	R1 ±SD	R2A	R2B	R2C	R2 ±SD	R3A	R3B	R3C	R3 ±SD
Ca <sup>2+</sup>	mg/L	69.54	68.93	68.75	69.07 ±0.41	65.86	65.01	65.43	65.44 ±0.42	66.47	66.16	65.36	66.00 ±0.57
Na <sup>+</sup>	mg/L	28.81	28.96	29.03	28.93 ±0.11	28.44	28.39	28.18	28.34 ±0.14	29.60	29.05	28.60	29.08 ±0.50
Mg <sup>2+</sup>	mg/L	4.98	4.59	4.78	4.78 ±0.19	6.62	6.62	6.60	6.61 ±0.01	4.60	4.40	4.45	4.48 ±0.10
K <sup>+</sup>	mg/L	1.77	1.80	1.77	1.78 ±0.01	1.67	1.66	1.63	1.65 ±0.02	1.78	1.79	1.81	1.79 ±0.01
CO <sub>3</sub> <sup>2-</sup>	mg/L	-	-	-	-	-	-	-	-	-	-	-	-
HCO <sub>3</sub> <sup>-</sup>	mg/L	378.17	376.17	376.17	376.83 ±1.15	388.37	384.30	378.17	383.61 ±5.13	378.20	382.27	382.27	380.91 ±2.35
Cl <sup>-</sup>	mg/L	10.00	10.00	10.00	10.00 ±0.00	10.00	10.00	10.00	10.00 ±0.00	10.00	10.00	10.00	10.00 ±0.00
SO <sub>4</sub> <sup>2-</sup>	mg/L	13.33	13.67	12.67	13.22 ±0.50	13.67	13.67	14.00	13.78 ±0.19	13.67	13.67	13.33	13.56 ±0.19
NO <sub>3</sub> <sup>-</sup>	mg/L	0.23	0.23	0.23	0.23 ±0.00	0.23	0.20	0.23	0.22 ±0.01	0.23	0.25	0.22	0.23 ±0.01
pH		8.10	8.01	8.02	8.04 ±0.04	8.01	8.00	8.05	8.02 ±0.02	7.93	7.96	7.96	7.95 ±0.01
Turbidity	NTU	0.02	0.03	0.03	0.03 ±0.01	0.04	0.04	0.04	0.04 ±0.01	0.03	0.03	0.03	0.03 ±0.00
Conductivity	µs	616	606	601	608 ±8	548	541	554	548 ±7	601	604	608	604 ±4
Temperature	°C	28.2	27.6	27.6	27.8 ±0.3	30.3	29.7	28.8	29.6 ±0.8	27.7	27.7	27.3	27.6 ±0.3



Parameter	Sample Number	R4A	R4B	R4C	R4 ±SD	R5A	R5B	R5C	R5 ±SD	R6A	R6B	R6C	R6 ±SD
Ca <sup>2+</sup>	mg/L	64.68	65.65	64.52	64.95 ±0.61	67.40	64.93	66.70	66.35 ±1.27	68.01	67.30	66.30	67.20 ±0.85
Na <sup>+</sup>	mg/L	26.13	26.37	26.25	26.25 ±0.12	28.87	28.16	28.59	28.54 ±0.36	25.80	25.69	24.95	25.48 ±0.46
Mg <sup>2+</sup>	mg/L	8.03	8.03	8.05	8.04 ±0.01	8.04	8.04	8.04	8.04 ±0.00	7.81	7.81	7.81	7.81 ±0.00
K <sup>+</sup>	mg/L	1.84	1.85	1.86	1.85 ±0.01	1.85	1.86	1.85	1.85 ±0.00	1.76	1.85	1.83	1.82 ±0.05
CO <sub>3</sub> <sup>2-</sup>	mg/L	-	-	-	-	-	-	-	-	-	-	-	-
HCO <sub>3</sub> <sup>-</sup>	mg/L	376.17	384.30	386.3 3	3.82.2 7 ±5.38	376.17	376.17	386.3 3	3.79.5 6 ±5.86	380.23	384.30	378.2 0	380.9 1 ±3.11
Cl <sup>-</sup>	mg/L	10.00	10.00	10.00	10.00 ±0.00	10.00	10.00	10.00	10.00 ±0.00	10.00	10.00	10.00	10.00 ±0.00
SO <sub>4</sub> <sup>2-</sup>	mg/L	14.33	14.00	13.00	13.78 ±0.69	13.50	13.25	13.38	13.38 ±0.12	13.67	14.33	13.67	13.89 ±0.38
NO <sub>3</sub> <sup>-</sup>	mg/L	0.05	0.02	0.03	0.03 ±0.01	0.03	0.03	0.03	0.03 ±0.00	0.13	0.15	0.14	0.14 ±0.01
pH		7.97	8.02	7.94	7.98 ±0.04	7.98	7.96	7.97	7.97 ±0.01	7.92	7.98	8.01	7.97 ±0.04
Turbidity	NTU	0.04	0.02	0.02	0.03 ±0.01	0.02	0.02	0.02	0.02 ±0.00	0.03	0.04	0.03	0.03 ±0.00
Conductivity	µS	591	596	594	594 ±3	595	595	595	595 ±1	594	596	599	596 ±3
Temperature	°C	26.5	27.3	28.1	27.3 ±0.8	27.7	27.9	27.8	27.8 ±0.1	28.5	28.3	29.2	28.7 ±0.4

**APPENDIX B**  
**LETTER OF APPROVAL**

1000 Mendocino  
1000 Mendocino



JABATAN PENDIDIKAN NEGERI SARAWAK  
BANGUNAN TUN DATUK PATINGGI  
TUANKU HAJI BUJANG  
JALAN SIMPANG TIGA  
93604 KUCHING  
SARAWAK

Telefon: 082-243201  
FAX: 082-246750  
Kawat : PENDIDIKAN

Ruj. Kami : 01/JP/2053/LAT(Kajian) Jld.VI  
Tarikh : 28 Julai 2003

**ENCIK TAMIZY BIN IBRAHIM**

Lot 1945, Lrg Temenggung Haji Gobil 6,  
Semariang Fasa 3,  
Jalan Sultan Tengah,  
93050 Petra Jaya,  
Kuching, Sarawak

Tuan,

**KEBENARAN UNTUK MENJALANKAN KAJIAN UNTUK PROJEK AKHIR DI JABATAN  
PENDIDIKAN SARAWAK**

Dengan hormatnya saya diarah merujuk kepada perkara di atas.

2. Sukacita dimaklumkan bahawa pada dasarnya Jabatan Pendidikan Sarawak tiada halangan untuk membenarkan tuan menjalankan kajian bertajuk "**GROUNDWATER GEOCHEMISTRY OF A SANDSTONE AQUIFER (KAYAN SANDSTONE) IN BAU – LUNDU AREA**" bagi tujuan projek akhir di Daerah Bau – Lundu. Walau bagaimanapun persetujuan perlu diperolehi dari pihak sekolah terlebih dahulu.

3. Sepanjang tempoh mendapatkan maklumat tersebut, tuan adalah tertakluk kepada peraturan yang sedang berkuatkuasa dan menjalankan kajian seperti tajuk di atas.

4. Jabatan ini memohon agar sesalinan laporan dihantar ke Unit Latihan, Jabatan Pendidikan Sarawak sebaik sahaja selesai untuk tujuan rekod dan rujukan. Dengan surat ini, Guru Besar sekolah terlibat adalah dimohon untuk memberi bantuan dan kerjasama yang sewajarnya bagi menjayakan kajian tersebut.

Sekian. Terima kasih.

**"BERKHIDMAT UNTUK NEGARA"**

Saya yang menurut perintah,

**(PONIMAN BIN BEJOK)**  
Sektor Pengurusan Perkhidmatan Pendidikan  
b.p Pengarah Pendidikan,  
Sarawak

s.k. Pegawai Pendidikan Bahagian  
Bahagian Kuching/Samarahan