



Faculty of Resource Science and Technology

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

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Bachelor of Science with Honours  
(Resource Chemistry)  
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- 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.



.....  
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## 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 were 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 meq/L	45.00 2.25	42.00 2.1	9.00 0.45	6.43 0.32
Na <sup>+</sup>	mg/L meq/L	17.00 0.74	27.00 1.17	4.00 0.17	68.19 2.96
Mg <sup>2+</sup>	mg/L meq/L	4.00 0.33	2.00 0.17	2.00 0.17	3.02 0.25
K <sup>+</sup>	mg/L meq/L	1.00 0.03	2.00 0.05	2.00 0.05	3.20 0.08
HCO <sub>3</sub> <sup>-</sup>	mg/L meq/L	241.00 3.95	286.00 4.69	61.00 0.99	820.5 13.45
SO <sub>4</sub> <sup>2-</sup>	mg/L meq/L	5.00 0.10	0.00 0.00	0.00 0.00	1.2 0.03
Cl <sup>-</sup>	mg/L meq/L	2.00 0.06	2.00 0.06	10.00 0.29	0.24 0.01
NO <sub>3</sub>	mg/L 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 “Kayan” 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 “Kayan” Sandstone from Literature.

A comparison of the groundwater investigated with other hydrogeochemical studies from the “Kayan” 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.

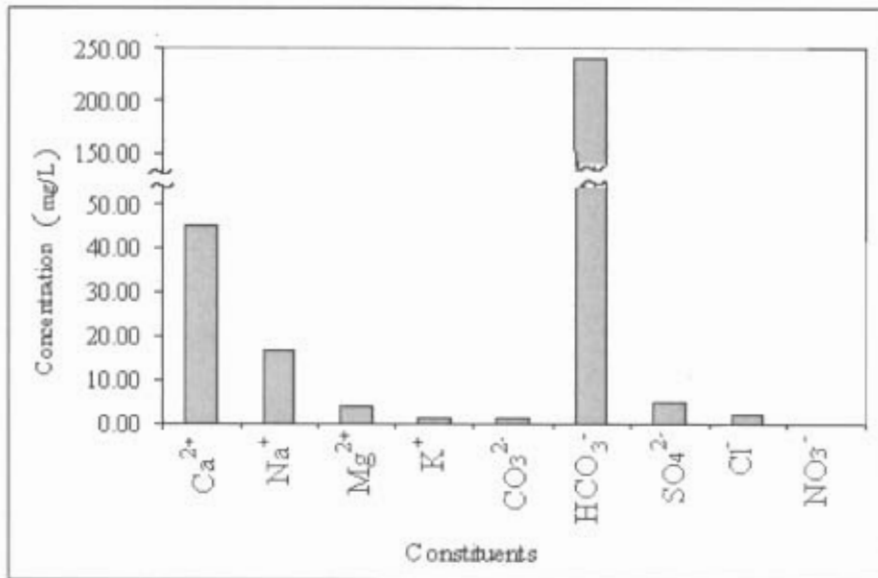


Figure 2 Analysis L1

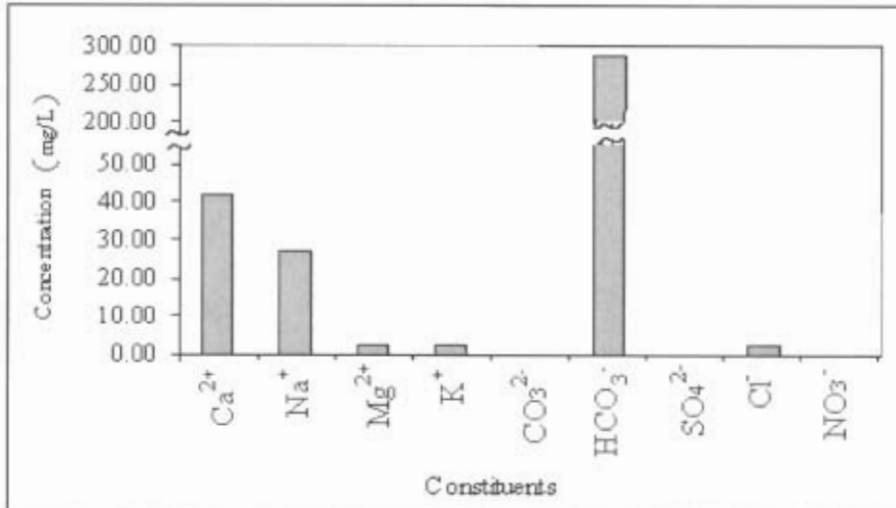


Figure 3 Analysis L2

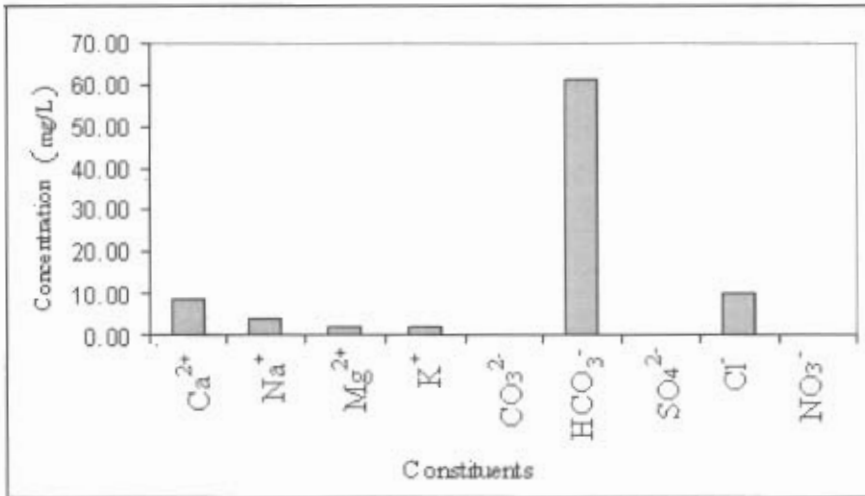


Figure 4 Analysis L3

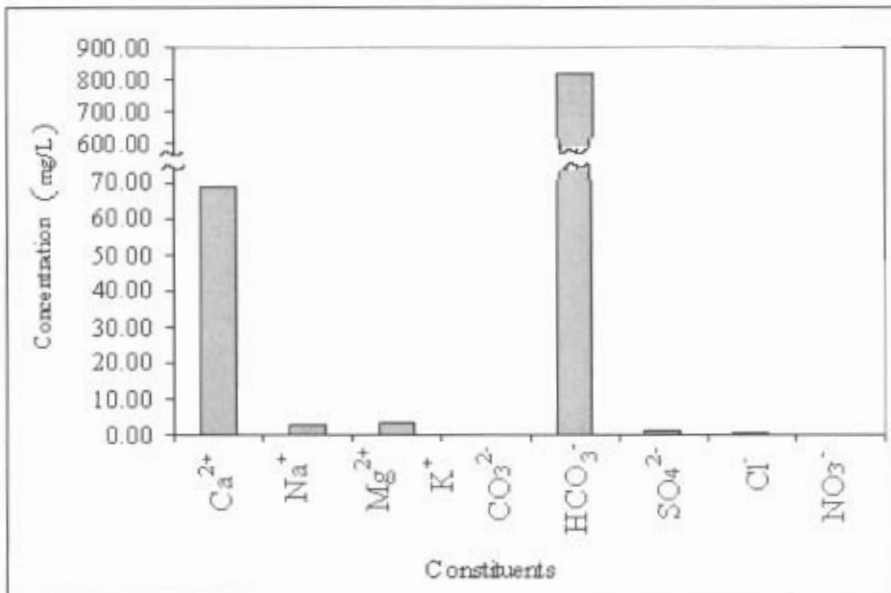


Figure 5 Analysis L4