SALINITY OF IRRIGATION WATER IN THE PHILIPPI FARMING AREA OF THE CAPE FLATS, CAPE TOWN, SOUTH AFRICA

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KEY WORDS

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Suitability

ABSTRACT

SALINITY OF IRRIGATION WATER IN THE PHILIPPI FARMING AREA OF THE CAPE FLATS, CAPE TOWN, SOUTH AFRICA

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This research investigated the nature, source and the spatial variation of the salinity of the water used for irrigation in the urban farming area of Philippi, which lies in the Cape Flats region of the Cape Town Metropolitan Area, South Africa. The irrigation water is mainly drawn from the Cape Flats aquifer, and pumped into ponds for eventual crop irrigation. Water samples were collected in summer and in winter from fifteen selected sites using standard water sampling procedures. Each site consisted of one borehole and one pond. The samples were routinely analyzed for salinity levels, and concentrations of major and minor ions. From the same boreholes and ponds, water was sampled in summer for isotope analysis to assess effects of evaporation on the water quality and salinity.

Descriptive statistics were used to display the variation in range of specific ions in order to compare them with the recommended ranges. Geographical Information Systems analysis described the spatial distribution of the salinity across the study area, and hydrogeochemical analysis characterized the various waters and detected similarities between the water samples in the study area and other waters found in the Cape Flats region. In addition, the US salinity diagram classification of irrigation water developed by Richards (1954) was used to assess the current suitability of groundwater and pond water samples collected during the entire sampling period for irrigation activities. The research indicated that the concentrations of some ions such as chloride, nitrate, potassium and sodium exceeded in places in the study area, the target range values set by the Department of Water Affairs and Forestry (DWAF, 1996) and the Food and Agriculture Organization (Ayers and Westcot, 1985). It revealed that borehole and pond water were mostly brackish across the area regarding their total dissolved salts content, and fresh water was only found in the middle part of the study area. The research found that sea water does not intrude into the aquifer of the study area, and the accumulation of salts in groundwater and soil in the study area is mainly due to the agricultural activities and partially due to the natural movement of water through the geological formation of the Cape Flats region. The conceptual model of the occurrence of the salinization process supported these findings.

From this investigation it is understood that the groundwater and pond water in the study area were generally suitable for irrigation purposes but they have to be used with caution as the vegetables are classified as sensitive and moderately sensitive to salt according to DWAF Irrigation water guidelines (1996). The quality of these waters was mainly affected by the land use activities.

August 2011

DECLARATION

I declare that ***Salinity of irrigation water in the Philippi farming area of the Cape Flats, Cape Town, South Africa***, is my own work, that it has not been submitted for any degree or examination in any other university, and that all the sources I have used or quoted have been indicated and acknowledged by means of complete references.

Cocou Davis Ruben AZA-GNANDJI August 2011

Signed: ……………………….

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ACRONYMS AND ABBREVIATIONS

Apr: April

Aug: August

BH: Borehole

CAB: Cation - Anion Balance

DWAF: Department of Water Affairs and Forestry

EC: Electrical Conductivity

ECe: Electrical Conductivity of the saturated soil extract

FAO: Food and Agriculture Organization

Feb: February

Fig: Figure

GPS: Global Positioning System equipment

GW: Groundwater

ID: Identity

Jun: June

NGDB: National Groundwater Database

Min: Minimum

Max: Maximum

P: Pond

SAR: Sodium Adsorption Ratio

TLC meter: Temperature, Level and Conductivity meter

TDS: Total Dissolved Salts

US: United States

USGS: United States Geological Survey

UWC: University of the Western Cape

WHO: World and Human Organization

WRC: Water Research Commission

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The main concern associated with water quality for irrigation purposes is the salinity. High salinity levels tend to affect soil structure and crop productivity mainly through limiting the uptake of water by plants. Salt contamination can cause adverse and permanent environmental impacts to soil and groundwater resources (Todd and Mays, 2005; Khodapanah et al., 2009). If vertical migration from the near surface soil through the vadose zone to the underlying water table occurs and salts reach groundwater, the ensuing degradation of the aquifer can result in its long-term loss of value as a source for public or private drinking water supply, irrigation, or industrial purposes. Understanding the impact of intensive irrigation in a well-defined catchment on water quality (i.e. salinity) is important in catchment management for both land use and water allocation. Salinization of groundwater and soil presents a critical problem for sustainability of irrigation agriculture (Tien et al., 2004).

An area that is often affected by these salinity issues in South Africa is the Philippi farming area in the Cape Flats region of the Cape Town Metropolitan Area. It is a vegetable producing area, and its crops are intensively irrigated with groundwater which is drawn from the Cape Flats aquifer. The Cape Flats aquifer is a primary unconfined aquifer, with a high, but under-utilized groundwater potential (Wright and Conrad, 1995). Several studies have been conducted in the Cape Flats but with little attention to understanding the salinity of water that is used for agricultural purposes, especially vegetables. With this oversight in mind, this study was conceived to investigate the salinization of water used for irrigation in the Philippi farming area that can potentially impede the crop productivity, especially in summer.

1.2 Statement of the problem

In the Western Cape, the agricultural sector is one of the largest users of water resources and the agricultural water demand increases annually (Adelana et al., 2006; Seward et al., 2009). The municipality of Cape Town often experiences water shortages during the dry summer months exacerbated by the area's rapid economic development and population growth (Adelana et al., 2006; Seward et al., 2009). The farmers generally have their own boreholes for water supply and irrigation. In the Philippi area, the boreholes are drilled into the Cape Flats aquifer. Some of the farmers in Philippi area reported that the water salinity increased in the summer months to levels that were detrimental to their crop yield.

Previous studies conducted in the Cape Flats region (e.g. Wright and Conrad, 1995; Adelana et al., 2010) indicated that groundwater in Philippi area had generally a fairly low salinity with the electrical conductivity values within the acceptable ranges set by the Department of Water Affairs and Forestry (DWAF) guidelines. However, analyses of water samples from boreholes and ponds performed by the commercial laboratory Bemlab Ltd for some farmers in the study area indicated that both borehole water and pond waters were unsuitable for irrigation activities under normal conditions as electrical conductivity values were largely out of the recommended ranges set by DWAF (Appendix 1).

In the study area, the severity of the spatial and temporal distribution of the salinity problem is unknown. Moreover, the Cape Flats aquifer represents a geohydrologically important resource that could potentially be exploited as a municipal water supply (Wright and Conrad, 1995; Seward et al., 2009). It is therefore important to monitor the groundwater resource and the pond water, and to better understand where, when and why the water becomes too salty for use in the study area. This research seeks then to investigate the nature, source and the extent of the salinity of the water used for irrigation in the Philippi farming area.

1.3 Research hypotheses

Salinity is a complex problem involving geology, topography, climate, groundwater, soils, vegetation and land use (Smithson and Acworth, 2005). Naturally, all groundwater contains salts in solution. The type and concentration of salts depend on the environment, movement, and source of the groundwater (Todd and Mays, 2005). Soluble salts in groundwater naturally originate primarily from dissolution of rock materials. Salinity, therefore, generally increases with depth and with time spent and distance travelled in an aquifer. Saline groundwater can also result from agricultural activities. Excess irrigation water passing through the root zone of cultivated areas and reaching the water table usually contains salt concentrations several times than that of the applied irrigation water due to the evapotranspiration process which tends to concentrate salts in drainage waters. In addition, the applications of fertilizers and soil amendments increase usually salt concentrations of percolating waters. Other sources of salinity in groundwater in coastal regions are the intrusion of sea water and airborne salts originating from the air-water interface over the sea (Todd and Mays, 2005). Groundwater in some geologic formations may also be naturally high in dissolved solids.

The reported summer-time cause of saline water at some farms in Philippi is unknown but, hypotheses explaining the salinity include:

- The high salinity results from the application of fertilizers and soil amendments.
- The high salinity results from water being pumped from in or near geologic formations with naturally high salinity.
- The high salinity results from seawater intrusion.
- The high salinity is due to the evaporation from the ponds.

1.4 Research goal and objectives

The main goal of this research is to contribute towards a better understanding of the nature, distribution and causes of the salinity of water used for agricultural activities in the Philippi farming area. Therefore, an integrated approach, combining several specific objectives was adopted in order to achieve the research goal. The objectives include:

- To use hydrochemical methods to characterize the chemical constituents of the borehole and pond water and to compare them with the chemical constituents of other waters such rain, seawater and water from non-irrigated areas in order to detect similarities and processes affecting water in the study area.

- To compare the concentration of the water constituents in the study area with the target ranges set by the Department of Water Affairs and the Food and Agriculture Organization so as to assess their suitability for irrigation use.
- To characterize the spatial and temporal distribution of the salinity of the borehole and pond water throughout the study area.
- To investigate the environmental processes affecting borehole and pond water by analyzing the stable isotopes of oxygen and deuterium.
- To investigate the origin of the salinity through assessment of seawater intrusion and the possible effects of agricultural activities.
- To develop a conceptual model of the salinity process in the study area.

1.5 Chapter outline

The layout of the thesis is as follows:

- Chapter one gives an introductory overview of the survey. The motivation, the hypotheses and the goal with the specific objectives of the research are presented.
- Chapter two describes physical characteristics of the study area. The geographical location, the geology, the hydrogeology, the climate and the land use activities are presented.
- Chapter three addresses the general concept of the water salinity. The source of salinity in natural resources, and the effect of high salinity in agricultural schemes are presented. The summary of some previous studies on the water salinity is included as well.
- Chapter four provides the methodological approach used to reach the goal and objectives of the study. The data collection, the study area selection and the various diagrams generated to analyze and interpret the gathered data are presented.

- In chapter five the analyses and the interpretation of the various data obtained during the literature search and collected over the course of the survey are discussed.
- Chapter six provides conclusion and recommendations emanating from the findings of the research.

CHAPTER 2

STUDY AREA DESCRIPTION

2.1 Introduction

The aim of this chapter is to introduce the area of interest. The chapter gives the geographical location and extent of the study area, and describes the geology, the geohydrology of the area's aquifer, the climate and the land use of the study area.

2.2 Geographical location and extent

The Philippi area is situated on the sandy Cape Flats, about 14 km from Cape Town, Western Cape, South Africa. It lies between the latitudes 34°00'S and 34°05'S, and longitudes 18°31'E and 18°36'E. It is bound to the north by Lansdowne Road, in the south by Strandfontein village, to the west by Strandfontein Road and to the east by Vanguard Drive (Figure 2.1) (Meerkotter, 2003). Philippi area is within the quaternary catchment area whose the topography is typical of coastal plain and dune fields.

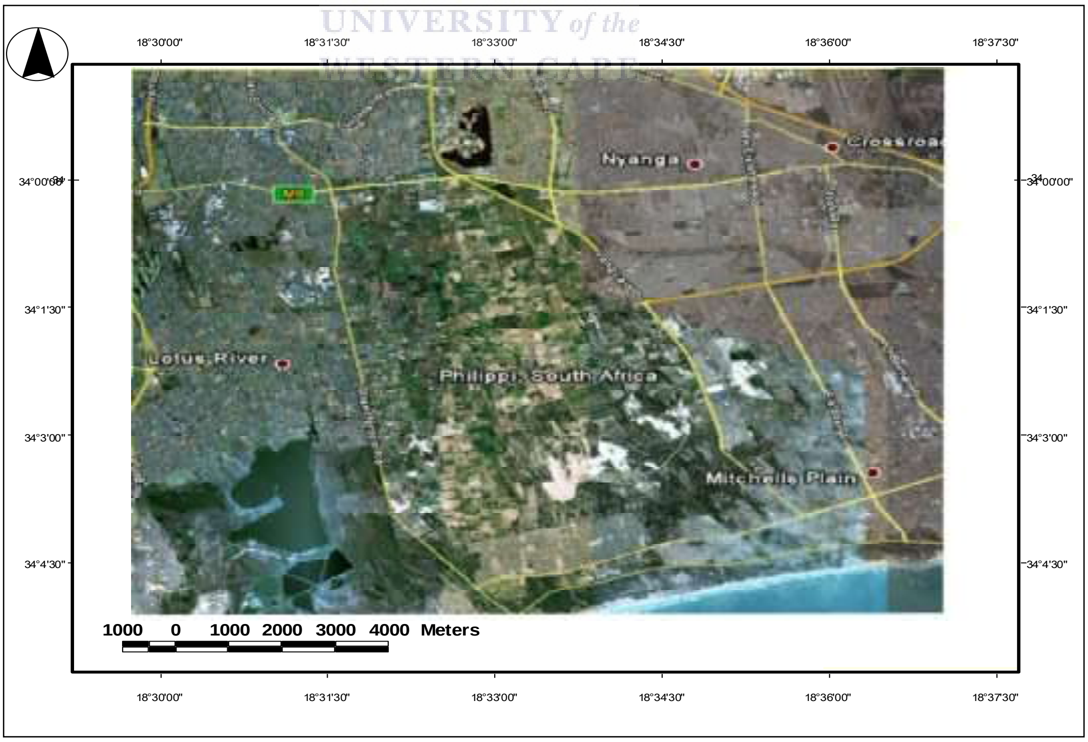


Figure 2.1: Satellite photo (Google Earth, 2009) of western South Africa showing the Philippi area.

2.3 Regional and local geology

Philippi area falls within the Cape Flats region. According to Wright and Conrad (1995), the Cape Flats aquifer consists of Cenozoic deposits underlain by essentially impervious Malmesbury Shale or Cape Granite. The sands, which cover an area of some 630 km^2, extend in a northerly direction along the West Coast. Sedimentation initially occurred in a shallow marine environment, subsequently progressing to intermediate beach and wind-blown deposits, and finally to aeolian and marsh (peat) conditions. A feature of the sediments is the presence of shelly material over most of the area. The sand body is generally stratified horizontally and several lithostratigraphic units can be recognized. Calcareous sands and surface limestone deposits cover portions of the area. While silcrete, marine clays and bottom sediments of small inland water bodies also occur sporadically.

Table 2.1 summarizes the different horizontal formations with their respective lithostratigraphic units of the Cenozoic sediments referred to as Sandvield group, and Figure 2.2 shows the geological map of the area around the Cape Flats, in the south-western Cape. The stratigraphic cross-sections based on previous and present information are presented in Figure 2.3 (Adelana et al., 2010).

Locally, the geological formation in Philippi is essentially constituted of the Springfontyn Formation which is Aeolian in nature and consists of fine to medium quartzose sand. Grain size often increases with depth and thin calcareous clay and peat lenses may be present in places (Wright and Conrad, 1995). The cross sections of the Philippi area show that the bedrock of the area is predominantly argillaceous weathered Malmesbury shale (Figure 2.3).

Table 2.1: The Cenozoic formation of the Western Cape

Group	Formation	Description	Age
Sandveld	Witzand	Aeolian, calcareous, quartzose sand	Holocene
	Langebaan (Wolfgat)	Aeolian, calcrete-capped, calcareous sandstone	Pleistocene
	Velddrif	Littoral, calcrete-capped coquina	
	Milnerton	Fluvial gravel, marine clay and littoral sand	
	Springfontyn (Philippi)	Aeolian, quartzose sand with intermittent peaty clays	
	Varswater	Quartzose and muddy sand, and shelly gravel, phosphate-rich	Pliocene
	Saldanha	Conglomeratic sandy phosphorite	Late Miocene
	Elandsfontyn	Angular quartzose gravely sand and peaty clays	Middle

Source: Adelana et al., 2010.

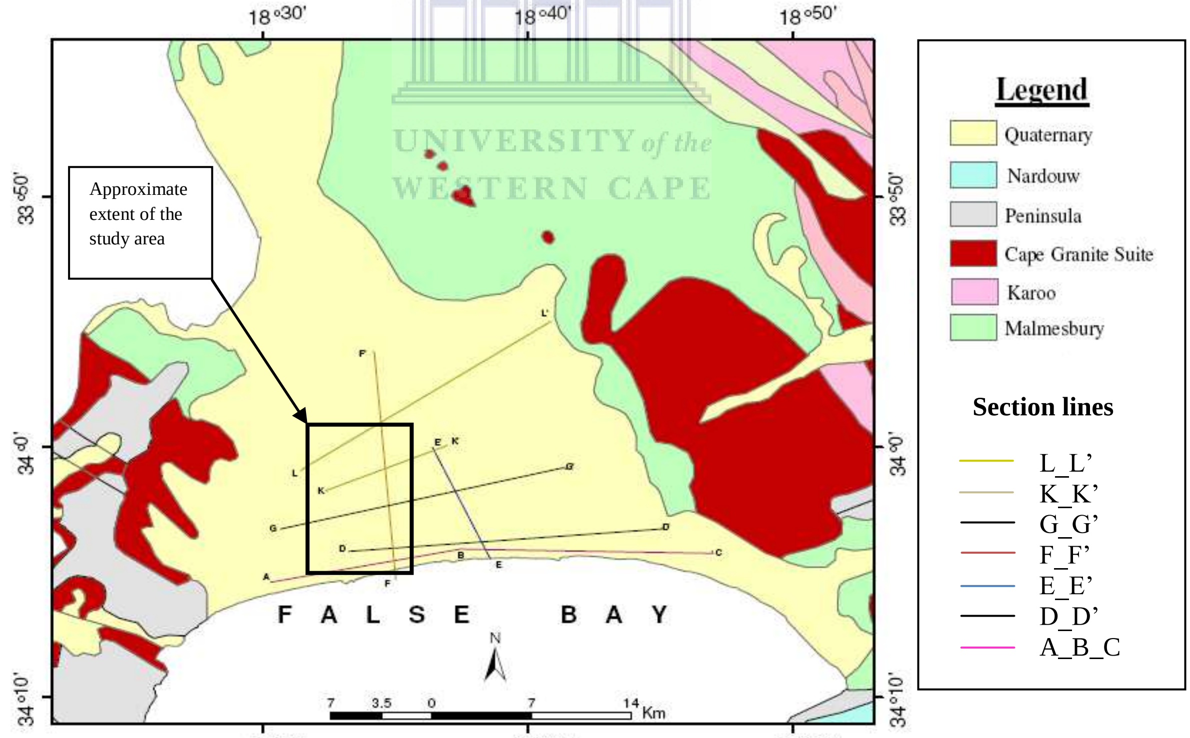


Figure 2.2: Geological map of the area around the Cape Flats (Adelana et al., 2010)

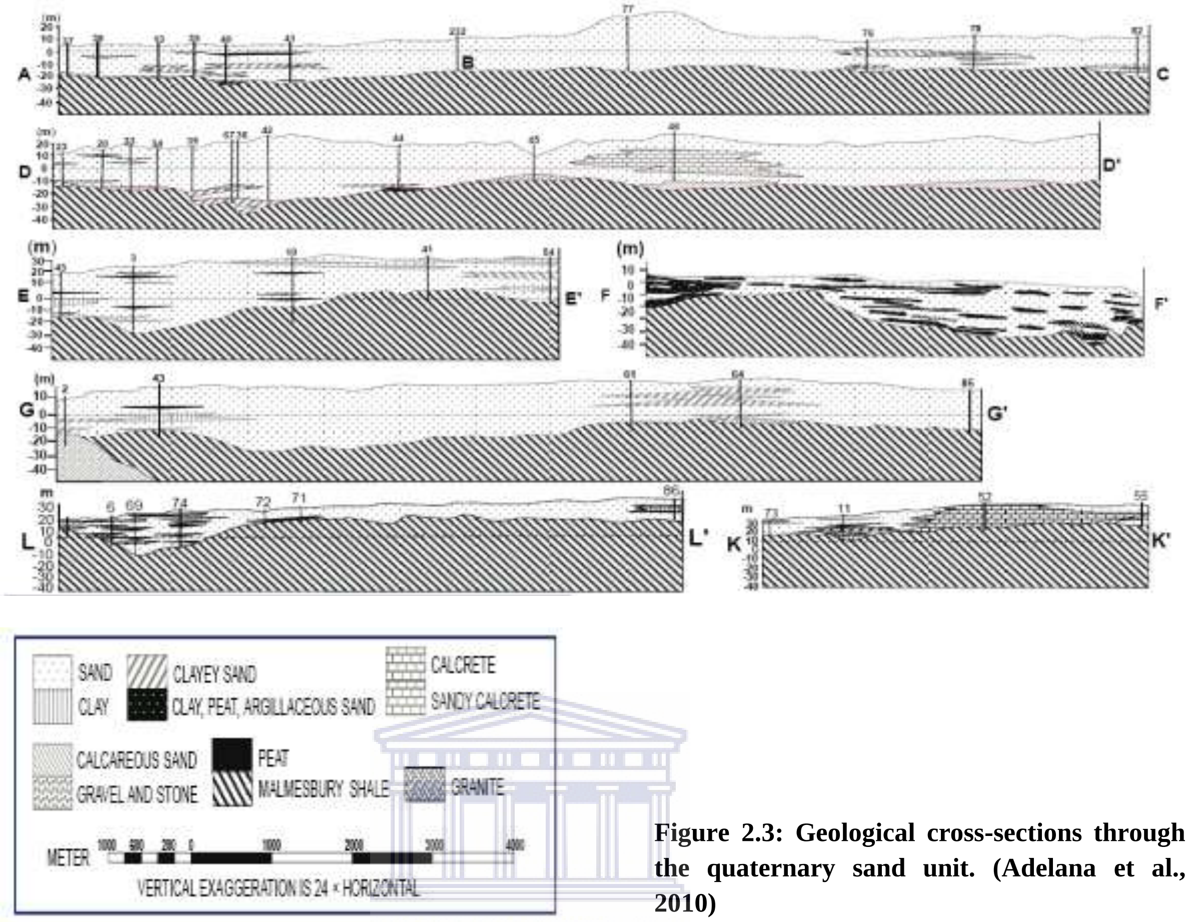


Figure 2.3: Geological cross-sections through the quaternary sand unit. (Adelana et al., 2010)

2.4 Geohydrology of the Cape Flats Aquifer

The main aquifer system characterizing the study area is the Cape Flats aquifer. According to Wright and Conrad (1995), the Sandveld Group deposits constitute what is known as the Cape Flats aquifer. The aquifer is regionally unconfined, and is essentially free of lateral hydraulic or geological boundaries, which may influence regional behaviour. The aquifer is not hydrogeologically linked to any other aquifer. It pinches out against "impermeable" boundaries in the east, west and north, while the coastline extending along False Bay, between Muizenberg and Macassar defines the southern boundary. The weathered bedrock has generally been considered as the impervious basement of the primary aquifer (Gerber, 1976; Wessels and Greeff, 1980). Sands of the Witzand and Springfontyn Formations constitute the major groundwater target. These sands range in size from fine to coarse and are generally well sorted and rounded. These formations do, however, possess a degree of heterogeneity and anisotropy due to vertical and lateral grain size graduation and the occurrence of sandy clay and clayey sandy lenses. The calcareous clay and calcrete layers of the Langebaan Formation, if present, act as a barrier and hinder the free flow of groundwater. This unit thus acts as an aquitard results in a semi-confined aquifer. The Varswater Formation can also be classified as an aquitard when the Witzand and Springfontyn Formations are present. (Vandoolaeghe, 1989). By virtue of this pelitic and extensively weathered nature of the Malmesbury metasediments, the bedrock is generally regarded as an impervious basement. The Malmesbury does, however, contain brittle sandstones and high yields have been obtained in these arenaceous units along the West Coast. Part of the groundwater abstracted in the Philippi agricultural area is derived from the bedrock. Wessels and Greeff (1980) also located a number of boreholes in the Eastern Cape Flats producing good yields and qualities out of the Malmesbury rocks. The aquifer is principally recharged from precipitation within the catchment. Average annual rainfall, which occurs mainly in winter and early spring, ranges between 500 to 800 mm across the Cape Flats. Groundwater flow in the Cape Flats is either west to Table Bay or south to False Bay. Water level contours suggest a lower hydraulic conductivity along the coast than inland. Transmissivity values, determined from investigations by Gerber (1976), ranged from 50 to 650 m^2/d, with typical values ranging between 200 and 350 m^2/d. The effective porosity was typically of the order of 0.10 to 0.12 but values of 0.25 were found over a large area. Vertical permeability was found to be smaller by a factor of 10 to 20 when compared with the horizontal permeability. Replenishment of the aquifer due to precipitation was calculated at 36×10^6 m^3 per annum and the losses by evapotranspiration are extremely high and exceed 80%.

2.5 Climate

The study area has a typical Mediterranean climate with cold, wet winters and warm, dry summers. The climate data from Cape Town Airport reveals annual precipitation of the Cape Flats area varies mainly between 400 and 800 mm. There is a dry period with less than 20 mm rainfall per month from November to March; the mean annual temperature is moderate, approximately 17°C. Summer temperatures are mild, with an average maximum of 26°C. The winter months are cool, with an average minimum temperature of 7°C (Adelana et al., 2010).

2.6 Land use

Philippi area is an agricultural area first settled by German vegetable farmers in the 19th century (Meerkotter, 2003). It is predominantly used for vegetable farming but other forms of farming include shrub and flower farming as well as poultry, pig and cattle farming. Additional activities include horse riding schools, stables and silica mining which occurs in the southern part of the area. Due to the growth of formal and informal settlements around Philippi area, the agricultural area has been reduced over the last decades but farming activities still prevail over the area (Meerkotter, 2003).

In Philippi farming area, the main vegetables that grow during both summer and winter season include carrots, cabbages, potatoes, lettuce, onions, peppers, beans, cauliflowers, spinaches and broccoli. Various manures/fertilizers and fungicides/pesticides are applied to facilitate the vegetables growth and protect them against the insects. To ensure that enough water is available for the growth of the crops throughout the year and to maintain the productivity level, the farmers have their own boreholes from which they pump the groundwater and store it in the ponds. The dimensions of the ponds vary generally between 40 to 80 meters for the length, 30 to 50 meters for the width and 3 to 10 meters for the depth. The ponds act as the reservoirs and contain water from boreholes, rainfall and sometimes irrigation return flow. Most of the ponds are underlain by plastic liners to avoid the leakage of the stored water especially at their bases. The pond water is later pumped to irrigate the adjacent crop. Figure 2.4 depicts some of the ponds and crops in the study area.

Figure 2.4 : Land use pictures

a. Cabbage crop
b. Carrot crop
c. Pond which was filling up with water from its related borehole
d. Pond well underlain by plastic liner
e. Pond underlain by plastic liner only at the bottom

CHAPTER 3

LITERATURE REVIEW

3.1 Introduction

An overview of the definition and source of salinity in water and soil resources has been given in this chapter. Effects of high salinity levels in agricultural schemes are highlighted, and some previous studies related to salinity of the natural resources are summarized in the last part of this chapter.

3.2 Definition of salinity

According to Bastick et al. (2003), salinity is the accumulation of excessive salts in land and water at sufficient levels to impact on human and natural assets (plants, animals, aquatic ecosystems, water supplies, agriculture, or infrastructure). Smithson and Acworth (2005) also defined salinization as the increase of salts in soil and water causing degradation and loss of land and water resources. They stated that salinity is a complex problem involving geology, topography, climate, groundwater, soils, vegetation, and land use.

The salinity of water is related to the concentration of the total dissolved salts in the water (Burger and Celkova, 2003). The higher is the total dissolved salts, the greater is the salinity. Based on the total dissolved salts (TDS) concentrations in water, Freeze and Cherry (1979) proposed the following simplified classification in Table 3.1.

Table 3.1: Classification of water based on the TDS concentration (according to Freeze and Cherry, 1979)

Water nature	TDS concentration (mg/L)
Fresh water	0 – 1000
Brackish water	1000 – 10000
Saline water	10000 – 100000
Hyper-saline water (or brine)	>100000

3.3 Source of salinity

Salinization is the process where the concentration of salts in water and soil is increased due to natural or human induced processes (Ghassemi et al, 1995; Smithson and Acworth, 2005). The occurrence of salinity in water and soil can be divided in two groups: primary salinity, where increases in salinity have occurred solely through natural processes; and secondary or induced salinity, where increases have occurred due to land use changes made by human activities (Smithson and Acworth, 2005; Omami, 2005).

3.3.1 Primary sources

Water and the geological formations through which water flows constitute a complex dynamic system in which any change of one part of the system is reflected on the other part (Cogho et al., 1989). Due to the interaction between water and rock, the natural movement of water through the porous media is often accompanied with the load of salt in water, and generally the concentration of salt in water increases with depth, time and distance travelled in an aquifer (Todd and Mays, 2005). In arid and semi-arid region, the evapotranspiration plays also a very important role in the increasing of salt's level in soil and water (Omami, 2005). Salt intrusion in groundwater and surface water is another natural type of salinization in coastal regions where the fluctuation of tides induces the displacement of the fresh water by the denser saline water (Omami, 2005; Todd and Mays, 2005).

3.3.2 Secondary sources

The secondary sources of salts in water and soils are related to human activities that impair (or affect) the quality of these natural resources. The main load of salt comes from the improper method of irrigation, salt build up in the soil unless the management of the irrigation system is such that salts are leached from the soil profile (Omami, 2005). Apart from irrigation practices, other sources that contribute to salt's load in soil and water caused by human activities include the following, but not limited to these ones:

- The landfills, tank and pipelines, liquid and solid waste disposals, spill and surface discharges, chemical manufacturing locations, petroleum refining locations, sewer disposals constitute some sources of pollution that can potentially accumulate salt into soil and groundwater (Todd and Mays, 2005). Through leakage process, these human activities may release considerable quantity of pollutants into the soil and further reach the groundwater.

- In coastal region where the aquifer is hydraulically connected to the sea, the overexploitation of boreholes in order to meet the water demand for various uses can disturb the natural hydrodynamic balance and the intrusion of salt water may occur in the aquifer (Todd and Mays, 2005).

3.4 Salinity problem in agriculture

Salinization of groundwater and soil presents a critical problem for sustainability of irrigation agriculture (Tien et al., 2004) as both the soil and water underneath crop's area can be affected inducing the reduction of the crop yield in many cases and the deterioration of the quality of groundwater for further use (Ayers and Westcot, 1985; Omami, 2005). In irrigation scheme management, the primary objective of the irrigation is to provide a crop with adequate and timely amounts of water, thus avoiding yield loss caused by extended periods of water stress during stages of crop growth that are sensitive to water shortages. However, during repeated irrigations, the salts in the irrigation water can accumulate in the soil, reducing water available to the crop and hastening the onset of a water shortage (Ayers and Westcot, 1985). Moreover, recharge brought about by seepage losses from the irrigation network and deep percolation from farm irrigation may accumulate salt into the underlying groundwater (Tanji and Kielen, 2002).

3.4.1 Effect of salinity on plants

The general response of plants to salinity is reduction in growth. Plant extracts water from the soil by exerting an absorptive force greater than that which holds the water to the soil. If the plant cannot make sufficient internal adjustment and exert enough force, it is not able to extract sufficient water and will suffer water stress. This happens when the soil becomes too dry (Omami, 2005). Salt in the soil-water increases the force that the plant must exert to extract water and this additional force is referred to as the osmotic effect or osmotic potential (Ayers and Westcot, 1985). Osmotic effects of salts on plants are a result of lowering of the soil water potention due to increasing solute concentration in the root zone. At very low soil water potentials, this condition interferes with the plant’s ability to extract water from the soil and maintain turgor (Romeo-Aranda et al., 2001; Omami, 2005).

All plants do not respond to salinity in a similar manner; some crops can produce acceptable yields at much greater soil salinity than others because of their ability to adjust the salinity and to extract more water from a saline soil (Ayers and Westcot, 1985). Plant salt stress resistance has been defined by Shannon and Grieve (1999) as the inherent ability of plants to withstand the effects of high salt concentrations in the root zone or on the leaves without a significant adverse effect. Sacher and Staples (1984) have defined salinity tolerance as the ability of a plant to grow and complete its life cycle on a substrate that contains high concentrations of soluble salt. This ability of plants to tolerate salinity depends on the interaction between salinity and environmental factors such as soil, water and climate conditions (Omami, 2005). For instance, many crops are less tolerant to salinity when grown under hot and dry conditions than under cool and humid conditions. Under hot and dry conditions yield will decrease more rapidly with increasing salinity compared to yield reduction under cool and humid conditions (Omami, 2005). Table 3.2 lists the salt tolerance parameters of some vegetable crops grown in the study area. Based on the classification of salt tolerance done by the Department of Water Affairs and Forestry (DWAF, Irrigation water guidelines, 1996), the vegetable crops grown in the Philippi study area can be classified as sensitive and moderately sensitive.

Table 3.2: Salt tolerance of some vegetable crops (Taken from annex 1: Crop Salt Tolerance data, Food and Agriculture Organization (FAO) Irrigation and Drainage Paper 61, 2002)

Vegetable	Threshold of the electrical conductivity of saturated soil extract (expressed in dS/m*)
Bean	1.0
Broccoli	2.8
Cabbage	1.8
Carrot	1.0
Cauliflower	---
Celery	1.8
Eggplant	1.1
Lettuce	1.3
Onion	1.0
Pepper	1.5
Potato	1.7
Pumpkin	---
Radish	1.2
Spinash	2.0
Sweet potato	1.5
Tomato	2.5
Turnip	0.9

*1dS/m=100mS/m

3.4.2 Irrigation water criteria

The suitability of water for irrigation is contingent on the effects of the mineral constituents of the water on both the plant and the soil (Todd and Mays, 2005). Salts may harm plant growth physically by limiting the uptake of water through modification of osmotic processes, or chemically by metabolic reactions, such as those caused by toxic constituents (Khodapanah et al., 2009). Specific limits of permissible salt concentrations for irrigation water cannot be stated because of the wide variations in salinity tolerance among different plants (Todd and Mays, 2005). However, in place of rigid limits of salinity for irrigation water, quality is commonly expressed by classes of relative suitability. The United States (US) salinity diagram with its sixteen classes developed by Richard (1954) is the recommended classification for the assessment of irrigation suitability. It takes into account the electrical conductivity and the sodium adsorption ratio (SAR) of the water. The SAR is directly related to the adsorption of sodium by soil as sodium reacts with soil to reduce its permeability (Todd and Mays, 2005). Beside the US salinity diagram, the Food and Agricultural Organization (Ayers and Westcot, 1985) proposed an extensive guideline to assess the suitability of the physico-chemical parameters of water for irrigation purposes. The Department of Water Affairs and Forestry (DWAF, 1996) through the water quality guidelines, Volume 4, also provided some target range values for assessing the levels of concentration of the constituents in the water used for irrigation activities in South African context. Table 3.3 lists the target range values of the concentrations of some physico-chemical parameters of water used for irrigation recommended by DWAF and FAO.

Table 3.3: Target range of the concentrations of some physico-chemical parameters of the irrigation water

Physico-chemical parameters of water	Target range
pH	6.5 – 8.4
EC	0 – 40 mS/m
Na^+	0 – 70 mg/L
Cl^-	0 – 100 mg/L
B	0 – 0.5 mg/L
NO_3^-	0 – 5 mg/L
Mn^{2+}	0 – 0.02 mg/L
Fe^{2+}	0 – 5 mg/L
K^+	0 – 2 mg/L*
Mg^{2+}	0 – 5 meq/L*
Ca^{2+}	0 – 20 meq/L*
HCO_3^-	0 – 10 meq/L*
SO_4^{2-}	0 – 20 meq/L*

* Values taken from Water Quality for Agriculture, FAO (Ayers and Westcot, 1985) as no information is available in DWAF guidelines for these constituents.

3.5 Salinity problem on the natural resources

The natural and the man-induced processes that contribute to load of salt in water and soil constitute an important environmental problem as salinity is a complex problem involving geology, topography, climate, groundwater, soils, vegetation, and land use (Smithson and Acworth, 2005). For instance, in Australia, salinity problem is a significant challenge to scientists and natural resource managers because of the enormity and widespread nature of the problem, the diversity of climatic regime, topography, geology and land use across which the problem occurs. It was noticed that the dryland salinity in the Murray-Darling Basin was a major cause of water quality decline and land degradation, and several other catchments in the country are predicted to have salinity levels that will exceed drinking water guidelines within the next 20 years (Smithson and Acworth, 2005).

Bastick et al. (2003) stated that some urban and peri-urban areas around Hobart (Tasmania) are currently under salinity threats because these areas contain zones with known saline groundwaters, saline seeps and scalds. In coastal area, salt water intrusion in the aquifer is well-known throughout the world. It is recognized that salt intrusion can cause significant economic and environmental problem and corrective actions required to suppress this problem are often extremely expensive (Todd and Mays, 2005).

3.6 Some previous studies related to salinity

Several studies have been conducted on the salinity of the soil, surface water and groundwater. Some relevant case studies are highlighted below.

Kirchner (1995) did an investigation of the contribution of groundwater to the salt load of the Breede River, using natural isotopes and chemical tracers. The Breede River catchment is one of South Africa’s primary vine and deciduous fruit growing areas. The greater portion of irrigated lands is situated in the middle part of the Breede River Valley between Worcester and Bonnievale. He used two approaches to assess the contribution of groundwater to the system and especially to the salt balance in the catchment namely: (i) compiling a salt and water balance from measurement and calculations of the contributions of the various components, and (ii) fingerprinting of groundwater by means of identifying certain chemical or isotopic properties unique to the groundwater in the area to obtain a measure of its contribution to the composition of the river water. He analyzed groundwater and surface water samples for their physical and chemical parameters, and their stable isotopic composition. His research indicated that chemical composition of water were variable in space and time. By producing Sodium Adsorption Ratio diagrams, he assessed the irrigation suitability of the waters in the area. The interpretation of the stable isotopes data indicated that groundwater from the various geologic formations of the catchment are less depleted in deuterium and oxygen-18 than the river water. His findings were that groundwater inflow played a minor role in the salinization of the Breede River, and that the water samples were influenced by process such as rainfall, evapotranspiration, the development of irrigated land, and the irrigation methods used.

Kortatsi and Jorgensen (2001) used hydrochemical data and isotopic composition of the groundwater to investigate the origin and distribution of saline groundwaters in the Accra Plains of Ghana. The region of Accra Plains contains the main industrial establishments of Ghana and provides one of the richest arable lands for large-scale agriculture in the country. Based on the Total Dissolved Salts (TDS) content, they found that groundwater salinity generally increased from north to south towards the coast but, however in the centre of the plain remote from the coast, there were a few very high TDS values. Their interpretation of isotopic composition and hydrochemical data revealed that very close to the coast, the salinity was mostly due to seawater intrusion; but elsewhere within the Plain, the high TDS was attributed to the dissolution of halite from the soil zone and evaporative concentration of water on the surface before recharge of groundwater occurs.

Smithson and Acworth (2005) did an investigation of unconsolidated sedimentary units and their role in the development of salinity in the Snake Gully Catchment, Central New South Wales, Australia. The Snake Gully catchment has significant erosion and salt affected land, with surface water flows and shallow groundwater containing high salinity level. They used an integrated approach combining a number of investigative techniques to satisfy their research objective. They applied a combination of geoscientific techniques including geological mapping, drilling, radiocarbon dating, particle size analysis, geophysics, groundwater monitoring and hydrochemistry to investigate fine grained unconsolidated sedimentary units and their role in the development of salinity in the Snake Gully Catchment. They found that gully erosion in the valley has exposed a series of sedimentary units with sharp textural contracts traditionally known as duplex soils thought to have been formed in-situ over 20 000 to 30 000 years. The interpretation of the hydrogeochemical data indicated sodium chloride dissolution and ion exchange were the main processes affecting the ionic concentration of shallow groundwaters in the catchment. They found through oxygen-18 and deuterium isotope results that evaporative concentration only affected surface waters, and was not significant in shallow or deep groundwaters in the catchment. They developed a number of conceptual models and found that clay-rich Aeolian derived from sediment units had a major role in the development of land and water salinization in the region.

Mitra et al. (2007) assessed the suitability of shallow groundwater for irrigation in sand dune area of northwest Honsh Island, Japan. They installed three observation boreholes made in Poly Vinyl Chroride with three plastic tubes to collect groundwater samples from three different depths. They gathered monthly water samples in 2005 and analyzed for the major and minor ions. They found that the TDS contents, the concentrations of Na^+, Ca^{2+}, and Mg^{2+} and total hardness in groundwater of the study area were decreasing with depth, and that revealed that anthropogenic activities might play a vital role for high values at upper groundwater. The research also indicated that groundwater of the study area was moderately hard, and was not suitable for irrigation under normal conditions.

Khodapanah et al. (2009) conducted the assessment of groundwater quality for different purposes in Eshtehard district, Tehran, Iran. They investigated the chemical characteristics of groundwater in Eshtehard district so as to evaluate the major suitability of water for drinking, domestic use and irrigation. They collected and analyzed water samples across the region for major and minor ions analyses. By statistically comparing the chemical concentrations of the constituents of water to the recommended concentrations set by the World Health Organization (WHO), they observed that the quality of groundwater was not suitable for drinking and domestic proposes in most parts of the region. They found that the water samples in most parts of the region groundwater were not suitable for irrigation under normal conditions while estimating and producing the percent sodium, Sodium Adsorption Ratio, Wilcox diagram and salinity diagram. They concluded that salinity was the principal concern in irrigated agriculture in the Eshtehard area, and the high salinity may be related to precipitation and dissolution processes within Miocene formations, evaporate deposits (gypsum and rock salt), overexploitation of groundwater and the high evaporation rate in the study area. For agricultural development, they suggested that special management of salinity control and certain kinds of plants with high salt-tolerance should be considered.

Chkirbene et al. (2009) investigated the hydrogeochemical characterisation of groundwater in the alluvial aquifer specifically the case of the Kurokawa aquifer, Tochigi Prefecture, Japan. The study area is a region which is known for intensive agricultural activities and groundwater is the main water resource used for drinking and irrigation purposes in the region. They carried out a field survey, and collected groundwater and surface water samples from uniformly distributed wells and representative river points for analysis of the various water quality parameters. They investigated the influence of land use on the hydrochemistry of groundwater through analyzing the water chemistry at selected points in the region. Using Piper diagrams and Stiff diagrams, they found that groundwater was mainly of the Ca – HCO_3 type and shallow meteoric water percolation type. They found that water chemistry seemed to be influenced by the topography of land and they classified the samples in three distinct groups as upland, floodplain and stream groups. However, in floodplain, denitrification processes and dissolution of dolomite could explain the groundwater chemical characteristics. In the downstream region, freshening phenomena and dilution processes seemed to be dominant.

Afroza et al. (2009) investigated the hydrochemistry and origin of salinity in groundwater in parts of Lower Tista Floodplain, Northwest Bangladesh. They collected groundwater from hand tube wells, shallow tube well and deep tube wells across the area. Through the analyses and interpretations of the water sample chemical data, they found that the hydrochemistry in parts of the Lower Tista Floodplain in northwest Bangladesh was dominated by alkalies and was weakly acid, having highest concentrations of sodium and bicarbonate cations and anions, respectively. Based on electrical conductivity (EC) values, they divided the area into the northern fresh groundwater zone (EC less than 1000µS/cm) and the southern saline (EC greater than 1000µS/cm) groundwater zone with a vertical profile of increasing salinity with depth. They found that rock weathering was affecting the water quality in the region, mostly carbonate weathering which was affecting the water quality with dolomite dissolution and calcium precipitation, through the analyses of the ion ratios of some major ions. They compared the water parameters to the recommended range values, and concluded that the groundwater was suitable for drinking, livestock consumption, and partially suitable for industrial purposes. A thorough assessment of irrigation suitability through the estimation of the Residual Sodium Carbonate, sodium percentage, and the construction of the Sodium Adsorption Ratio diagram, revealed that groundwater was mostly unsuitable to poor suitability for irrigation purposes. They also suggested that groundwater could be used for agricultural activities if salt tolerant plants could be cultivated and special management for salinity control, with a particular drainage system, could be applied.

Kacmaz and Nakoman (2010) evaluated the quality of shallow groundwater for irrigation purposes in the Koprubasi uranium area. The study area, Koprubasi area, is a district of Manisa Province in the Aegean region of Turkey and the shallow groundwater located in this area is generally used for irrigation purpose by village inhabitants. For assessing the quality of the shallow groundwater in the area, they collected groundwater samples from the uranium mineralization area in Koprubasi and analyzed them for their physicochemical parameters. Based on the results, they found that the shallow groundwater in the study area seemed to be suitable when compared with Food and Agriculture Organization quality criteria for irrigation. Regarding the calculated Sodium Adsorption Ratio, the magnesium hazard and the Residual Sodium Carbonate, their research indicated good to permissible use of groundwater for irrigation activities. However, as the shallow groundwater is located in uranium mineralization area, they recommended that the water was not suitable for irrigation in order to prevent possible effects of uranium on human health.

Adomako et al. (2010) did the geochemical and isotopic studies of groundwater in the Densu River Basin (DRB) of Ghana. The Densu River Basin is an important agricultural area in Ghana and has a high population density. They investigated the geochemical characteristics and evolution, as well as recharge processes in the

DRB system with regard to the tectonics, geomorphology, lithology and flow system. They used mainly hydrochemistry, environmental isotopes and a series of comprehensive data interpretation methods (e.g. statistics, ionic ratios), and Piper diagrams to obtain a better understanding of the functioning of the system. They identified that the main factors controlling the water quality of the groundwater system were weathering of silicate minerals, dissolution, ion exchange, and to a lesser extent, evaporation, which seems to be more pronounced down gradient of the flow system. The variation measurements of the environmental isotopes (^{18}O, ^{2}H, ^{3}H) further, revealed that groundwater in the DRB was a relatively well-mixed system. However, deviation from the rainwater signature indicated combined local processes such as direct percolation through preferential channels, evaporation, and probable surface water and anthropogenic contribution to the system.

CHAPTER 4

METHODOLOGY

4.1 Introduction

A comprehensive approach to understanding the salinity of the water used for irrigation in the Philippi farming area was adopted. The research plan was mainly centered on the hydrogeochemistry of the area's aquifer, the spatial and the temporal distribution of the salinity, the origin of the salinity, the suitability of the waters for irrigation purposes and the conceptual model to explain the water salinity encountered in the study area.

The study incorporated the following main steps in the research:

- Desk study.
- Fieldwork.
- Interpretation of data.
- Conceptualization of a model of the salinity process.

4.2 Desk study

4.2.1 Review and data collection

The review was focused on the search for literature on the salinity of water used for irrigation purposes. Sources of literature data used in this phase include published and unpublished reports, both local and international.

The collection of the relevant available data related to the research was made. Major local sources include Department of Water Affairs and Forestry (DWAF), National Groundwater Database (NGDB) and Water Research Commission (WRC) among others. The types of acquired data include borehole data, topographical maps, articles and reports among others.

4.2.2 Statistical and hydrogeochemical analysis

The description statistics that include the minimum, the maximum, the arithmetic mean and the standard deviation have been used to compile the data gathered during the entire sampling campaign and during the literature's search for comparison purposes.

Various methods and graphics were used in the survey to analyze and interpret these data in order to better understand and assess the salinity problem encountered in the study area. The resulting diagrams are discussed further in this chapter.

4.3 Field work

4.3.1 Site selection

A lot of boreholes and ponds are present in Philippi farming area and they belong to different farmers. Owing to budget constraints not all of them could be sampled. Guided by areal distribution and accessibility granted by the farmers, fifteen sites were selected to be part of the survey. Figure 4.1 depicts the sampling points in the study area and Table 4.1 gives the coordinates of the selected sites with some information of their boreholes.

The farmers that allowed the water sampling on their properties were telephonically contacted each time two days before going to the field.

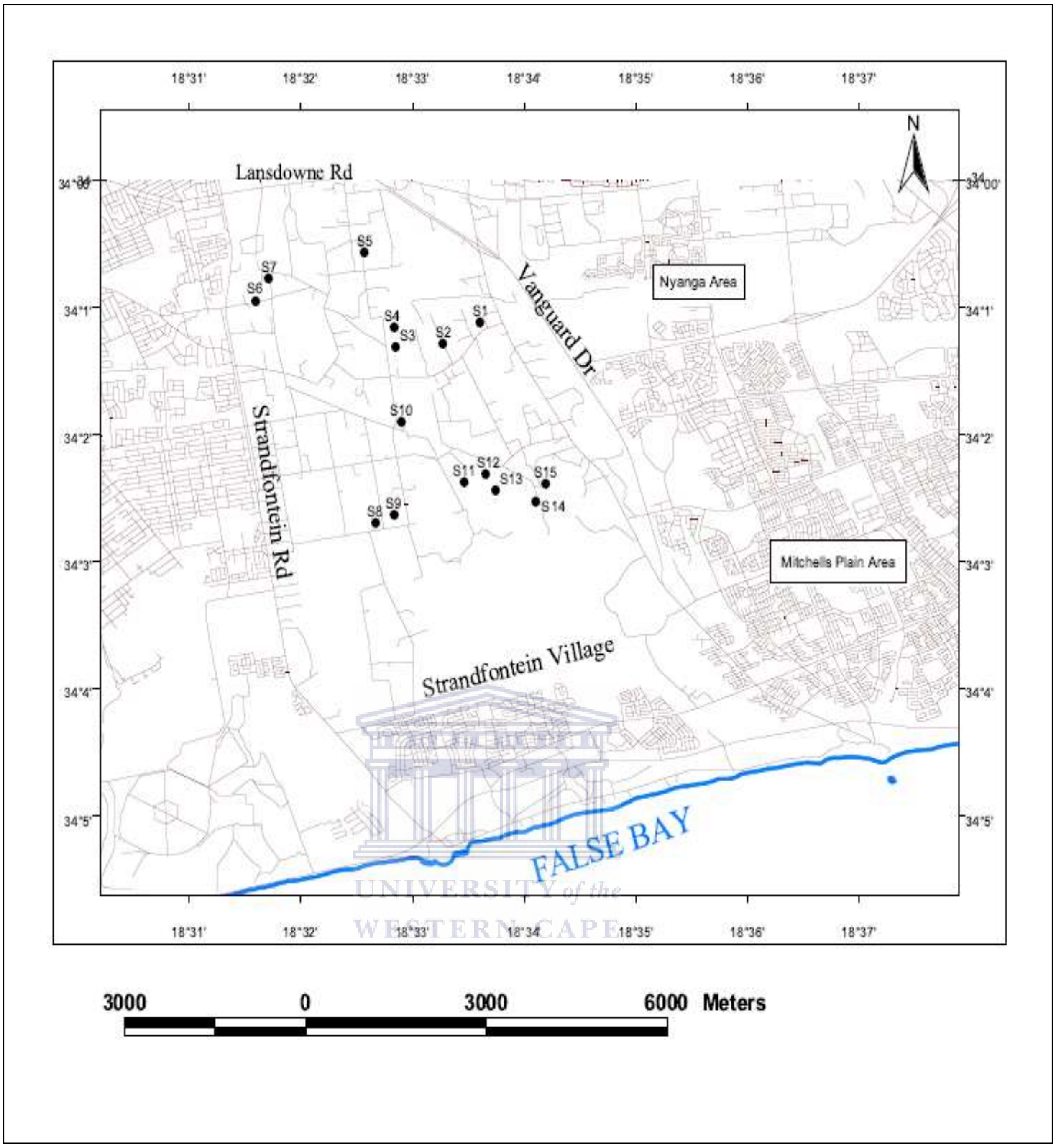


Figure 4.1: Location of the sampling points.

Table 4.1: Geographical coordinates of the sampling points

Site	Farmer Name	Longitude ''E''	Latitude ''S''	Approximate distance to the shore line (km)	Approximate depth of the borehole (m)
S1	Rix Leon	18.56017	-34.01883	7.52	40 to 60
S2	Rix Leon	18.55460	-34.02150	7.55	50
S3	Bock	18.54743	-34.02202	7.45	40
S4	Bock	18.54730	-34.01940	7.76	60
S5	Meyer	18.54293	-34.00968	8.94	40
S6	Rix Igor	18.52657	-34.01589	8.58	38
S7	Rix Igor	18.52861	-34.01295	8.83	38
S8	Hesterman	18.54448	-34.04497	4.97	35 to 50
S9	Hesterman	18.54727	-34.04393	5.02	35 to 50
S10	Bock	18.54842	-34.03182	6.37	100
S11	Terblanchi	18.55781	-34.03962	5.39	40 to 50
S12	Terblanchi	18.56096	-34.03850	5.33	40 to 50
S13	Carl	18.56253	-34.04080	5.06	30 to 40
S14	Heins	18.56846	-34.04219	4.75	100
S15	Heins	18.56994	-34.03986	4.97	40

4.3.2 Identification of the sampling sites

The coordinates of each sampling point were taken using the Global Positioning System equipment (GPS) in order to locate them on a map. Each site contained a pond with its related borehole and adjacent cropping area. These coordinates were taken at the beginning of the survey and were also taken during each session of field work to check whether the sampling was still being made at the same selected sites.

4.3.3 Sampling

Water sampling consisted of obtaining samples from the different selected sites in order to examine the water quality and its salinity level in the study area. Water samples were collected from boreholes and ponds for routine water analysis on a bi-monthly basis. In order to see the seasonal variation of water salinity and quality, sampling occurred in summer (February and April 2010) and in winter (June and August 2010). Water samples were also taken for stable environmental isotope analysis in summer season (February 2010). This latter analysis was expected to investigate hydrological processes by examining the effect of evaporation on borehole and pond water in the study area.

The water sampling complied with the procedures of water sampling developed by Weaver et al. (2007).

4.3.4 Collection, storage and transportation of water samples

The collection of the samples went from site S1 to site S15, the order in which the sites were labeled. It usually took one or two days.

The water was collected in the 300 milliliters (mL) plastic bottles for the routine water analysis of the major and minor ions. It was also collected in 150 mL plastic bottles for isotope analysis. The bottles for isotope analysis were fully filled and their caps were tightly fitted in order to remove entrapped air as much as possible. Before being filled, all the bottles were rinsed two or three times with a small amount of the collected water. The bailer was used first to bring up the water from ponds and then to fill the bottles (Figure 4.2). Each time, distilled water was used to rinse and clean two or three times the bailer after it was used to take particular water.

As the boreholes were operating for feeding and maintaining enough water in the ponds, the borehole water samples were collected at the outlet of the pipe connected to the boreholes. To ensure that the samples taken truly represented the water from the bulk aquifer within the borehole is tapped, the electrical conductivity (EC) and temperature values were monitored until they became stable before the sample was collected. The pond water was considered as surface water so the samples were directly collected without monitoring any physical parameter of the water.

The identity, date and type of analysis that was to be carried out, were labeled on the bottles using permanent marker. Then, the samples were immediately packed in the bucket containing some ice blocks in order to chill and maintain them at or below 4°C and they were not exposed to the direct sunlight as recommended by Weaver et al. (2007).

At the end of each day of field work, the water samples were packed into the refrigerator at the Department of Environmental and Water Science at the University of the Western Cape. A few days later; they were shipped to the commercial laboratory Bemlab Ltd in Somerset (South Africa) for ion analysis, and to the chemical analysis laboratory of the University of the Witwatersrand Johannesburg (South Africa) for isotope analysis.

a. **b.**

Figure 4.2: Pictures showing the bailer being used

a. Bringing up of the pond water
b. Filling up of the bottle

4.3.5 Other measurements

Besides the water sampling, the physical parameters such as electrical conductivity and temperature were directly measured in the field by using the TLC meter (Figure 4.3). As the boreholes were operating in the farms, the EC values were monitored until they became stabilized before recording the EC value with its corresponding temperature. Depending on the size of the pond, two to four measurements were taken and averaged. The TLC meter was carefully calibrated with the 1413µS/cm EC calibration fluid for each field trip in order to get reliable data.

a. **b.**

Fig 4.3 : Pictures showing the TLC meter being used

a. Recording of the EC and temperature values

b. Rolling up of the equipment's tape

4.3.6 Interview

At each farm, a short interview was conducted according to the questionnaire compiled to gain information about the farms and farming practices in the study area (Appendix 2). The interview was useful to find out which vegetables were cultivated and to better describe the land use in the study area.

4.4 Interpretation of data

4.4.1 Hydrogeochemical data

4.4.1.1 Water quality control

Water and the geological formations through which water flows constitute a complex dynamic system in which any change of one part of the system is reflected in the others (Cogho et al., 1989). Chemical analyses are commonly used to assess the interactions between these various components and also to determine whether water meets various standards for use by humans or to support aquatic ecosystems (Schwartz and Zhang, 2003).

As all waters contain a number of soluble ions, depending on their electric charge these soluble ions can be divided into anions and cations. Various options are offered for the tabulation of chemical data. They can either be tabulated in milligrams per liter (mg/L) or in milliequivalents per liter (meq/L) in tables. As the water is electrically neutral thus before a hydrochemical evaluation is done, the ionic balance of the respective chemical analyses is carried out to check the accuracy of the analyses (Cogho et al., 1989).

Several procedures for checking the accuracy of analyses are applicable to water samples for which relatively completed analyses have been done. Two different procedures were used in this survey to assess the credibility of the performed analyses before they were used for the interpretations.

The first check, most used, is based on the principle of electroneutrality which states that water cannot carry a net electrical charge (positive or negative) but must always be electrically neutral. When expressed as milliequivalent per litre (meq/L), the sum of positively charged species has to match with the sum of negatively charged species in the given water sample (Younger, 2007). This check is made by calculating the cation-anion balance (CAB) of each water sample analysis results, which is defined as:

$$CAB(\%) = 100 \times \frac{(sum\ of\ cation\ concentrations) - (sum\ of\ anion\ concentrations)}{(sum\ of\ cation\ concentrations) + (sum\ of\ anion\ concentrations)}$$

Where all the concentrations are expressed in milliequivalent per liter (meq/L)

The conversion in milliequivalent per litre is made by dividing the given concentration in mg/L by the molecular weight and the valence of the considered species.

$$meq/L = \frac{mg/L}{FormulaWeight/IonicCharge}$$

Younger (2007) states the following:

- If a CAB value is less than 5%, then the analysis can be regarded as sufficiently accurate for all uses.
- If a CAB lies in the range 5 - 15%, then the analysis should be used with caution.
- While those analyses with CAB values greater than 15% cannot really be regarded as being sufficiently reliable to justify using them for serious scientific purposes.

The second procedure commonly used to check the correctness of analyses is the correlation of measured electrical conductivity (EC) against ion sums. This procedure is based on the fact that the higher the EC, the higher the concentration of ions in water as the EC is related to the ions which are present in solution (Appelo and Postma, 1996). Both the anion and cation sums expressed in milliequivalent per liter should correlate positively with the electrical conductivity such that they fall on a straight line.

4.4.1.2 Interpretation

Tables showing results of analyses of chemical quality of groundwater are sometimes difficult to interpret, particularly when more than a few analyses are involved. To overcome this, graphic representations are useful for displaying purposes, for comparing analyses, and for emphasizing similarities and differences. Graphs can also aid in detecting the mixture of water of different compositions and in identifying chemical processes occurring as groundwater moves (Todd and Mays, 2005).

The diagrams used to interpret the results of water analysis in order to reach the objectives of the survey included the following:

4.4.1.2.1 Piper diagram

Piper diagram is one the graphs that are used to interpret the variations in water quality. It provides a convenient method to classify and compare water types based on the ionic composition of different water samples. Cation and anion concentrations for each water sample are converted to total meq/L and plotted as percentages of their respective totals on two triangles. The cation and anion relative percentages in each triangle are then projected into a quadrilateral polygon that describes the water type or hydrochemical facies (Zaporozec, 1972; Hem, 1985; Chkirbene et al., 2009; Kirchner, 1995; Todd and Mays, 2005).

Piper diagrams made for the survey were generated using a specific Microsoft Excel spreadsheet downloaded from the USGS website. For comparison purposes, the chemical constituents of other waters gathered during the literature’s search such as rainwater, spring water, sea water and water from non-irrigated areas of Cape Flats region were plotted as well on the same Piper diagrams made for the water samples collected during the sampling campaigns in order to detect similarities in their chemical compositions.

4.4.1.2.2 Stiff diagram

The ionic composition of water samples can also be represented by the type of water quality diagram called Stiff diagram. Stiff diagrams are used to compare the ionic composition of water samples between different locations, depths, or aquifers. The Stiff diagram is a polygon created from three horizontal axes extended on both sides of a vertical axis. Cations are plotted on the left side of the axis and anions are plotted on the right side, both in meq/L. A greater distance from the vertical axis represents a larger ionic concentration. The cation and anion concentrations are connected to form an asymmetric polygon where the size is a relative indication of the dissolved-solids concentration (Stiff, 1951; Alexander, 1972; Hem, 1985; Kirchner, 1995; Tonjes et al., 1995; Appelo and Postma, 1996; Todd and Mays, 2005; Chkirbene et al., 2009).

Stiff diagrams made for the survey were generated using Microsoft Excel. For comparison purposes, the Stiff diagrams of the chemical constituents of other waters gathered during the literature’s search such as rainwater, spring water, sea water and water from non-irrigated areas of Cape Flats region were made with the Stiff diagrams of the water samples collected during the sampling campaigns in order to detect similarities in their chemical compositions.

4.4.1.2.3 Sodium Adsorption Ratio diagram

Also called the United States (US) salinity diagram, the sodium adsorption ratio diagram is developed by Richards (1954) and is used to assess the suitability of water for irrigation purposes. Irrigation water with high sodium content can replace the exchangeable cations, Ca^{2+} and Mg^{2+}, of clay minerals in the soil. Soils which become saturated with sodium tend to lose their fertility and their permeability. The ability of water to exchange Ca^{2+} and Mg^{2+} with Na^+ is expressed by the sodium adsorption ratio (Richards, 1954):

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$$

The ion concentrations in the equation are expressed in meq/L.

In the Sodium Adsorption Ratio (SAR) diagram, which is subdivided into 16 different fields, the electrical conductivity is plotted against the sodium adsorption ratio on a semi-logarithm scale. Each field indicates different salinity and sodium exchange hazards. Depending on soil types and irrigation practices, this ratio gives an indicator of which crops can be grown under the circumstances (Cogho et al., 1989; Kirchner, 1995).

SAR diagrams made for the survey were generated using Microsoft Excel.

4.4.1.2.4 Contour maps

Contour facilities are used to depict the areal distribution of any numerical parameter in a two or three dimensional plane. They can be used either quantitatively or qualitatively to interpret the temporal and spatial variations in water quality (Cogho et al., 1989; Kirchner, 1995).

In order to display the temporal and spatial distributions of the water salinity in the study area for the compiled summer and winter data collected, contour maps of the water salinity were made by using the kriging approach of the software SURFER 8.

4.4.1.2.5 General graphics

General graphics are used to represent relationships between various parameters (Cogho et al., 1989; Kirchner, 1995). They were made in order to display the variations of concentration of the chemical constituents of water used for irrigation activities in the study area and to compare their range and arithmetic mean values with the recommended target values set by the Department of Water Affairs and Forestry Irrigation water guidelines (DWAF, 1996) and by the Food Agriculture Organization (Ayers and Westcot, 1985). General graphics in this survey were generated using the Microsoft Excel and the Statistical Package for Social Sciences.

4.4.2 Isotopic data

Isotopes can be divided broadly into stable and radiogenic varieties. The stable isotopes are used mainly for flow system tracing and climate reconstruction whereas the radiogenic isotopes are used to give the date of the groundwater (Schwartz and Zhang, 2003). This research focused on the stable isotopes oxygen-18 (^{18}O) and deuterium (^{2}H, or simply “D”).

The fractionation of oxygen-18 and deuterium in water samples provide a useful tool for investigating processes that have affected surface and groundwater systems (Smithson and Acworth, 2005). Stable environmental isotopes, oxygen-18 and deuterium contents, are measured as the ratio of the two most abundant isotopes of a given element. This is reported in delta (δ) notation as permil ($^{0}/_{00}$), which represents the deviation from a standard. The following general equation is used to calculate the deviation of the isotope ratios from a standard:

$$\delta \%_{00} = \frac{R_{sample} - R_{standard}}{R_{standard}} \times 100$$ (Schwartz and Zhang, 2003)

The oxygen-18 and deuterium content are usually measured with respect to the SMOW (Standard Mean Ocean Water) standard (Fritz and Fontes, 1980; Schwartz and Zhang, 2003). The fractionation of the stable isotopes in this survey was calculated in the chemical analysis laboratory of the University of the Witwatersrand Johannesburg.

The plotting of the oxygen-18 and deuterium data for the waters sampled in the study area was made with reference to the global meteoric water line in order to assess the deviation in oxygen-18 and deuterium from this line. The equation for that line is approximately: $\delta^{2}H = 8 \times \delta^{18}O + 10$ (Craig, 1961; Schwartz and Zhang, 2003). However, values differ for different parts of the world as the variation in the equation for the meteoric line at a specific location is a function of its climate, geographic location and the source region of the evaporation (Smithson and Acworth, 2005). Diamond and Harris (1997) found that Western Cape meteoric water defines a meteoric water line with the approximate equation $\delta^{2}H = 6.1 \times \delta^{18}O + 8.6$.

4.5 Conceptualization of a salinity model process

In the study area, water is pumped from the aquifer and stored in the ponds which are like reservoirs. Later the stored water is repumped to irrigate the sub-adjacent crop area. After irrigating the fields, water is taken by plants for growth, some is evaporated, some is returned to ponds and the remaining percolated to recharge the aquifer. During rain, the ponds are directly filled up and the aquifer is recharged. Then the water is pumped again from the aquifer to feed the ponds and the same process continues.

A conceptual model was briefly developed to explain the salinity in the water used for irrigation in the Philippi farming area. How water was circulating for irrigation activities and the possible scenarios of the occurrence of the accumulation of salt in the natural resources in the study area were examined based on the findings of the research on the one hand, and the literature’s search on the other hand.

CHAPTER 5

RESULTS AND DISCUSSION

5.1 Introduction

This chapter presents the results obtained from the analyses done on water at the different sampling points of the study area. An integrated approach was used to investigate the suitability of the various waters for irrigation purposes and the possible origins of the salinity in the study area. The spatial distributions of the salinity across the study area were discussed; and through the interpretation of the stable isotopes, the physical processes affecting groundwater and pond water were established. A conceptual model was briefly developed on the occurrence of the salinity in the study region in the last part of this chapter.

5.2 Quality control of the chemical analysis of the water

The two different procedures described in the methodology chapter, were applied in this section to assess the credibility of the performed analyses before they were used for the interpretations.

For the water samples collected, most of the cation-anion balance (CAB) values are less than 10% and only few data of June sampling are comprised between 10% and 15%. The two samples of June sampling campaign with CAB values greater than 15% have been discarded as they could not really be regarded as being sufficiently reliable to justify using them for serious scientific purposes as stated by Younger (2007). Tables 5.1a, 5.1b, 5.1c and 5.1d in Appendix 3 include the results of the analyses performed by the commercial laboratory Bemlab Ltd and the results of the calculated CAB are given in Tables 5.3a, 5.3b, 5.3c and 5.3d in Appendix 3. Table 5.3e summaries the CAB values.

The second procedure commonly used to check the correctness of analyses is the correlation of measured electrical conductivity (EC) against ion sums, as from Figure 5.1a to Figure 5.4b. This procedure is based on the fact that the higher the EC, the higher the concentration of ions in water as the EC is related to the ions which are present in solution (Appelo and Postma, 1996). Both the anion and cation sums should correlate positively with the electrical conductivity such that they fall on a straight line. The data fits were good as R^2 values were close to 1 (Figures 5.1a to 5.4b).

These above two procedures of the credibility check showed good results which suggest that the overall performed analyses of the water samples were sufficiently reliable to justify the use for further analyses.

Table 5.3e: Summary the CAB values

ORIGIN	CAB (%)			
	FEB	APR	JUN	AUG
BH 1	-4.941	NS	NS	NS
BH 2	-3.178	NS	NS	NS
BH 5	-2.057	-2.091	-6.172	-0.785
BH 6	-3.338	-2.141	NS	-1.137
BH 8	-2.404	-1.124	-8.115	NS
BH 9	2.813	2.061	NS	NS
BH 10	-2.775	0.139	NS	-5.388
BH 11	-7.255	-0.744	-3.884	-2.644
BH 12	-4.078	-0.654	NS	-3.956
BH 13	-3.950	-0.781	-4.600	-2.929
BH 14	-2.753	0.417	NS	NS
BH 15	2.126	0.660	-3.008	-2.232
P 1 A	-5.085	NS	NS	NS
P 1 B	-5.208	NS	NS	NS
P 3 A	-5.915	-2.784	-7.124	-6.700
P 3 B	-3.663	-1.803	-7.184	-4.538
P 4 A	-2.568	-3.326	-6.725	-6.182
P 4 B	-0.993	-2.348	-5.253	-5.947
P 5 A	-2.012	-1.989	-5.376	-2.226
P 5 B	-4.461	-1.475	-4.074	-2.085
P 6 A	-3.754	-2.960	-5.306	-3.450
P 6 B	-2.926	-1.899	-5.322	-3.428
P 7 A	-6.139	-2.971	2.969	-4.331
P 7 B	-7.639	-3.754	4.921	-4.021
P 8 A	-4.978	-3.475	***-14.785***	-3.363
P 8 B	-1.569	-0.909	***-16.199***	-4.460
P 9 A	-3.003	-0.437	***-14.821***	-4.401
P 9 B	-2.068	-2.753	***-13.525***	-3.298
P 10 A	-7.088	-3.329	-1.720	-7.580
P 10 B	-9.975	-4.272	-3.437	-8.155
P 11 A	-1.469	-3.168	***-16.541***	-5.796
P 11 B	-3.570	-2.296	-9.336	-5.096
P 12 A	-4.868	-3.411	***-13.822***	-3.004
P 12 B	-4.276	-2.647	***-11.693***	-4.692
P 13 A	-2.494	-3.026	***-14.201***	-1.397
P 13 B	-3.802	-1.849	***-13.953***	-3.030
P 14 A	-4.407	-1.372	-5.822	-2.689
P 14 B	-4.923	-0.101	-9.172	-3.406
P 15 A	-5.501	-1.358	-6.257	-5.359
P 15 B	-1.313	-2.965	-5.118	0.018

NS: No Sample

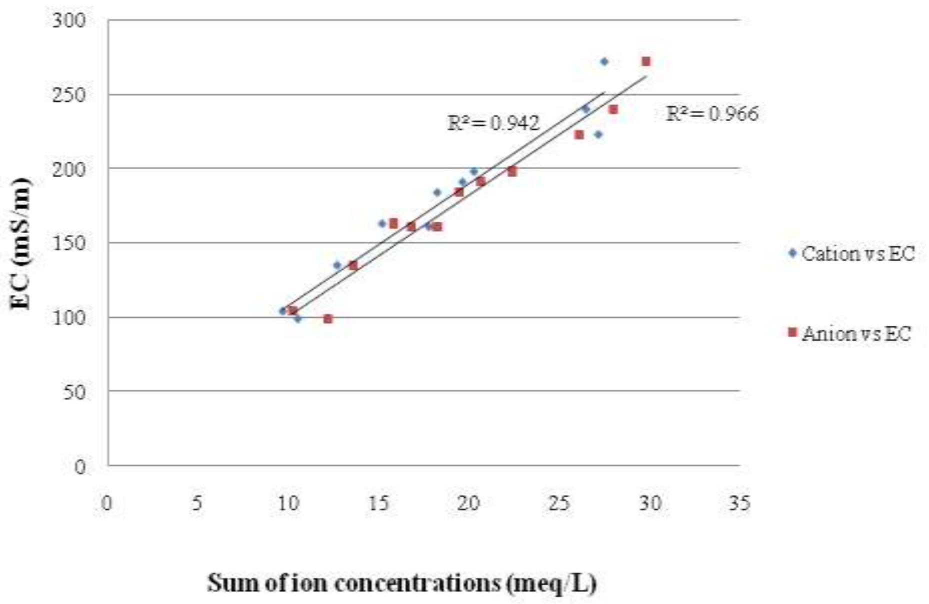


Fig 5.1a: Correlation between the sum of ion concentations and the EC (BH, Feb)

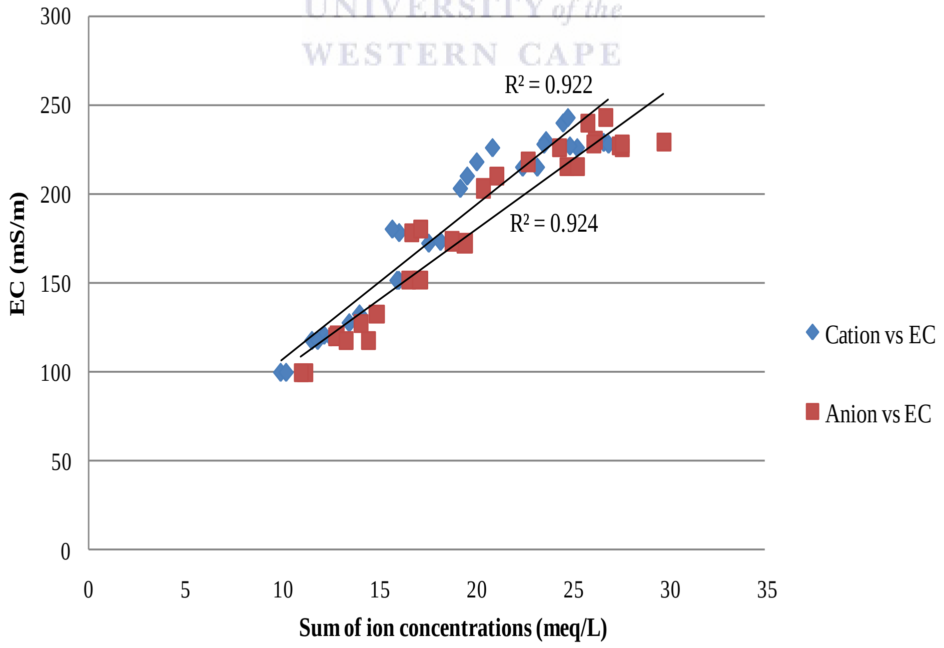


Fig 5.1b: Correlation between the sum of ion concentations and the EC (Pond, Feb)

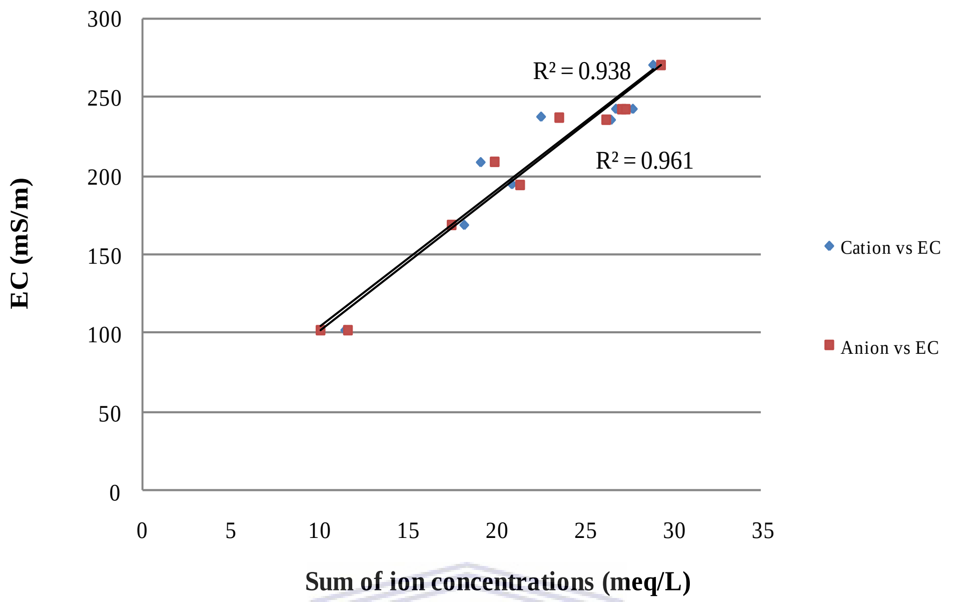


Fig 5.2a: Correlation beteween the sum of ion concentrations and the EC (BH, Apr)

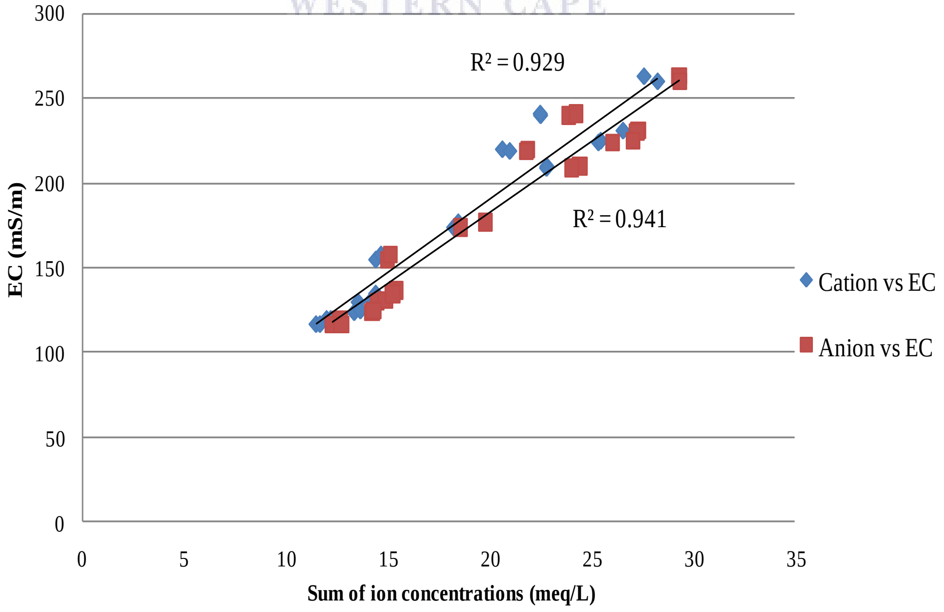


Fig 5.2b: Correlation beteween the sum of ion concentrations and the EC (Pond, Apr)

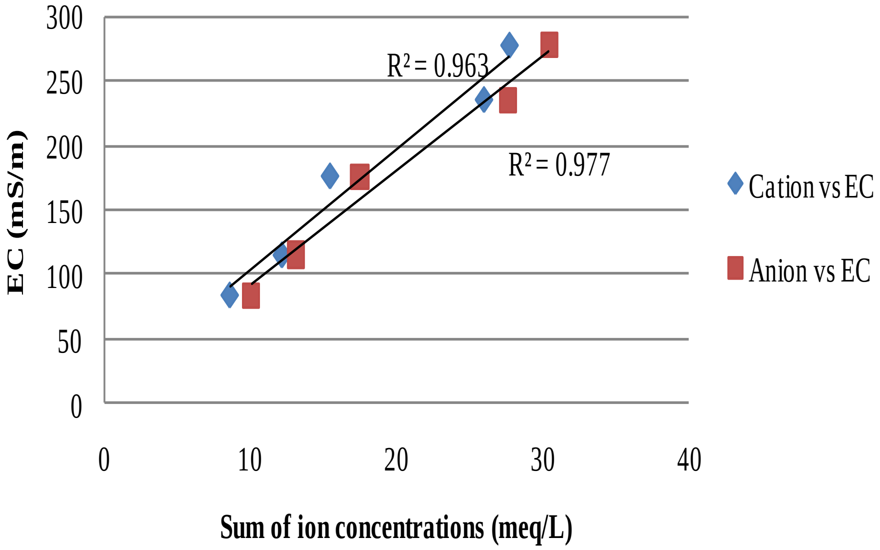


Fig 5.3a: Correlation between the sum of ion concentrations and the EC (BH, Jun)

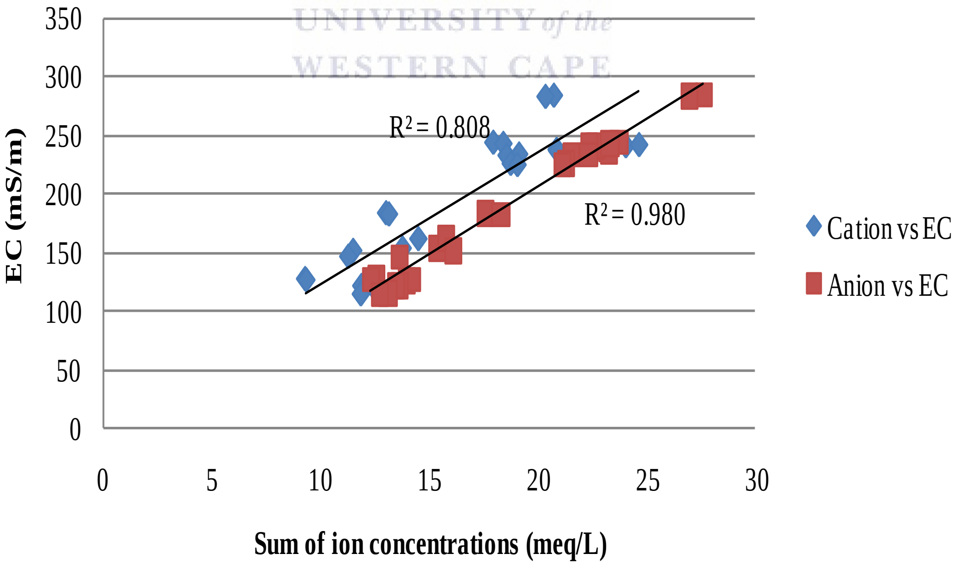


Fig 5.3b: Correlation between the sum of ion concentrations and the EC (Pond, Jun)

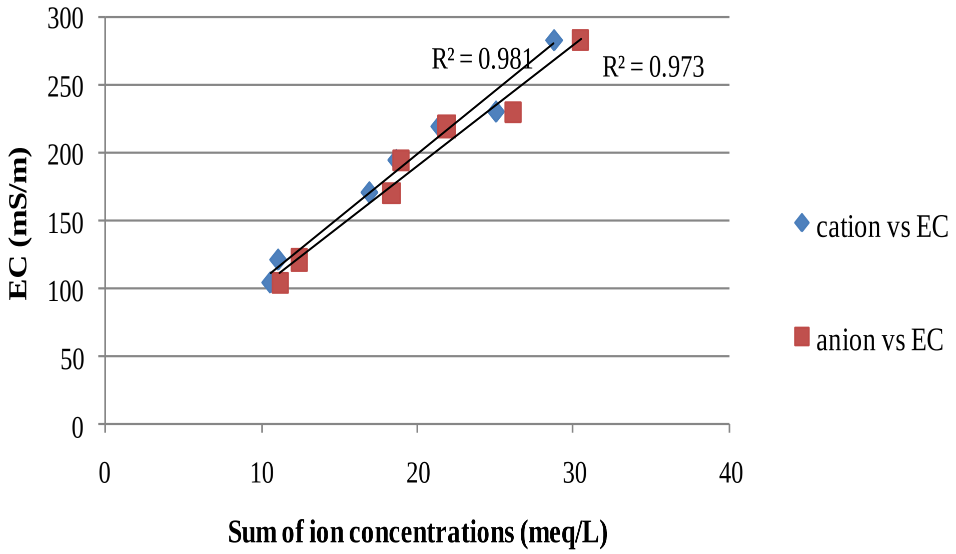


Fig 5.4a: Correlation between the sum of the ion concentrations and the EC (BH, Aug)

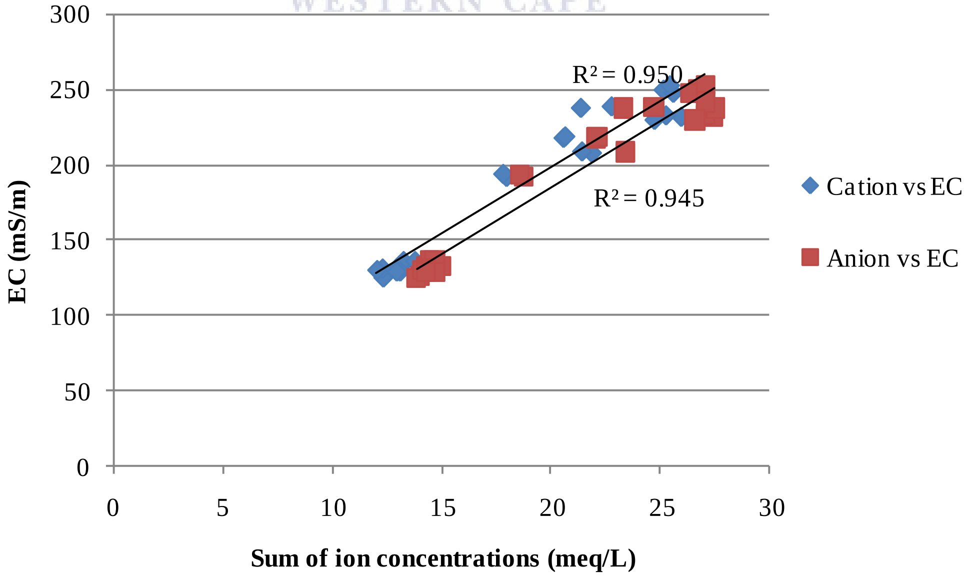


Fig 5.4b: Correlation between the sum of ion concentrations and the EC (Pond, Aug)

5.3 Hydrogeochemistry

Hydrogeochemical data was presented, analyzed and interpreted in this section. Statistical analyses of the data set were used to interpret some features characterizing the borehole and the pond water used for irrigation activities in Philippi area. For comparison purposes, the chemical constituents of other waters such as rainwater, spring water, sea water and water from non-irrigated areas of Cape Flats region have been discussed as well in this section in order to detect similarities in their chemical compositions.

5.3.1 Rain water composition

The rain water represents particular water for the survey as it is found on the Cape Flats and the concentrations of its constituents can be compared to those of the water samples collected during the survey in the study area. Table 5.4 in Appendix 3 includes the concentrations of the rain water constituents sampled at the research site of the University of the Western Cape, at iThemba site and in Belhar.

5.3.2 Spring water composition

The spring water represents particular water for the survey as it is found on the Cape Flats and the concentrations of its constituents can be compared to those of the water samples collected during the survey in the study area. Table 5.4 in Appendix 3 includes the concentrations of the spring water constituents sampled in Maitland.

5.3.3 Sea water composition

The sea water represents particular water for the survey as it is found on the Cape Flats and the concentrations of its constituents can be compared to those of the water samples collected during the survey in the study area. Table 5.4 in Appendix 3 includes the concentrations of the sea water constituents. For plotting purposes, the constituent concentrations of the sea water were divided by 50 as they are much higher than those of the other waters.

5.3.4 Water composition from non-irrigated areas

Water from non-irrigated areas of the Cape Flats region represents particular water for the survey as it is found on the Cape Flats and the concentrations of its constituents can be compared to those of the water samples collected during the survey in the study area. Table 5.4 in Appendix 3 includes the constituent concentrations of the groundwater sampled from boreholes in non-irrigated areas such as the University of the Western Cape Research Site (UWC 4, UWC 5) and iThemba site (PT 1, PT 2, PT 3, PT 4).

5.3.5 Water chemistry in Philippi farming area during the survey period

Statistical analyses for the interpretation of large data sets are commonly used in hydrogeochemical studies (Ashley and Lloyd, 1978; Adams, 1999). The statistical approaches applied were as follows:

- The descriptive statistics that give an overview of the maximum, minimum and the arithmetic mean of the chemical composition of the borehole and pond water collected during the sampling period in the study area. The arithmetic mean and ranges of the water constituent concentrations were compared with the target ranges set by Department of Water Affairs and Forestry (DWAF) Irrigation water guidelines, and by Food Agriculture Organization (FAO) guidelines. The boxplot diagrams that display the minimum, lower quartile, median, upper quartile, maximum and outlier values of a variable were generated and discussed for the chemical constituents of the borehole and pond water collected during the sampling period in the study area.
- The data sets were analyzed to find some processes affecting the water quality by interpreting the Stiff and Piper diagrams, and to assess the suitability of water for irrigation activities by considering the US salinity diagrams.

5.3.5.1 Descriptive statistics

An overview of the descriptive statistics of the groundwater and the pond water for the entire sampling period is summarized with the recommended ranges set by DWAF and FOA in the Table 5.6. Detailed results are presented in Tables 5.5a, 5.5b, 5.5c and 5.5d in Appendix 3. Figure 5.5 below, shows the legend of the boxplot diagrams.

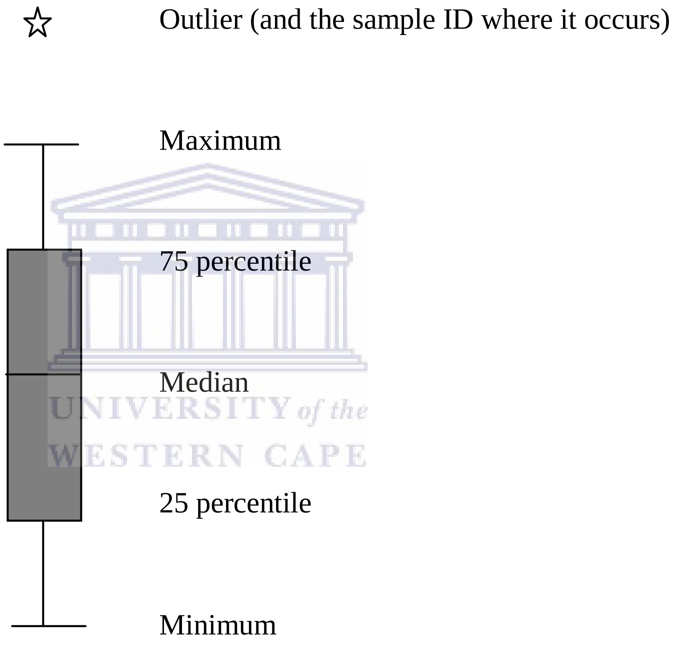


Fig 5.5: Legend of the boxplot diagrams

Table 5.6: Descriptive statistics of the parameters of the groundwater and the pond water for the entire sampling period

Water parameters	Boreholes								Ponds								target range
	Feb		Apr		Jun		Aug		Feb		Apr		Jun		Aug		
	Var. Range	Mean	Var. Range	Mean	Var. Range	Mean	Var. Range	Mean	Var. Range	Mean	Var. Range	Mean	Var. Range	Mean	Var. Range	Mean	
pH	7.0 - 7.7	7.4	6.7 - 7.8	7.4	6.7 - 7.5	7.1	6.6 - 7.5	7.1	7.3 - 8.4	7.8	7.7 - 8.3	8.0	6.9 - 8.0	7.5	6.8 - 8.6	7.8	6.5 – 8.4
EC	99 - 272	178	102 - 271	201	85 - 278	178	104 - 284	189	99 - 243	181	117 - 263	180	115 - 284	190	125 - 253	191	0-40 mS/m
Mg^{2+}	0.8 - 2.9	1.9	0.9 - 3.2	2.3	0.7 - 2.9	1.9	0.9 - 3.2	2.1	1.1 - 3.1	2.1	1.2 - 3.2	2.2	1.1 - 3.3	2.0	1.2 - 3.1	2.2	0-5 meq/L*
Ca^{2+}	4.4 - 19.5	11.0	4.2 - 18.3	11.4	5.4 - 18.7	11.0	5.0 - 17.4	9.7	4.9 - 19.1	10.1	4.2 - 18.7	9.6	5.2 - 14.4	8.8	5.7 - 17.3	10.0	0-20 meq/L*
HCO_3^-	2.0 - 6.4	5.0	1.4 - 5.5	4.3	3.0 - 6.0	5.1	2.6 - 6.0	5.0	1.6 - 6.0	4.2	2.3 - 6.2	4.4	2.8 - 7.2	5.0	2.3 - 7.4	5.2	0-10 meq/L*
Na^+	38.8 - 173.4	109.7	47.6 - 279.4	150.9	39.6 - 197.4	102.8	50.3 - 221.4	144.7	60.3 - 208.4	125.6	54.7 - 309.2	142.0	31.6 - 286.3	105.6	58.1 - 268.5	137.2	0-70 mg/L
Cl^-	98.0 - 480.3	266.7	96.9 - 643.3	330.7	102.2 - 481.1	259.9	99.6 - 495.2	316.5	143.0 - 499.8	297.9	126.9 - 630.9	300.4	138.3 - 571.9	303.6	138.3 - 563.1	301.5	0-100 mg/L
B	0.00 - 0.11	0.04	0.05 - 0.16	0.11	0.03 - 0.14	0.09	0.04 - 0.16	0.10	0.03 - 0.12	0.06	0.06 - 0.16	0.11	0.00 - 0.18	0.06	0.06 - 0.20	0.12	0-0.5 mg/L
K^+	5.7 - 68.4	28.5	8.1 - 74.8	35.5	3.8 - 57.6	27.2	6.3 - 65.0	29.5	15.7 - 59.7	35.4	15.5 - 53.2	35.2	19.6 - 58.6	30.3	20.6 - 75.6	45.3	0-2 mg/L*
SO_4^{2-}	1.4 - 14.8	6.5	1.3 - 14.9	7.5	1.5 - 15.5	7.3	1.7 - 13.4	5.9	0.6 - 16.3	5.9	1.5 - 15.2	5.8	1.1 - 10.2	4.5	1.6 - 15.1	6.2	0-20 meq/L*
NO_3^-	0.0 - 10.0	2.3	0.0 - 10.0	3.8	0.0 - 10.0	2.4	0.0 - 10.0	4.0	0.0 - 34.0	9.3	0.0 - 25.0	6.5	0.0 - 58.0	23.8	1.0 - 73.0	28.1	0-5 mg/L
Mn^{2+}	0.00 - 0.05	0.02	0.00 - 0.09	0.02	0.00 - 0.01	0.01	0.00 - 0.02	0.01	0.00 - 0.09	0.03	0.00 - 0.07	0.02	0.00 - 0.02	0.01	0.00 - 0.04	0.01	0-0.02 mg/L
Fe^{2+}	0.04 - 9.3	1.06	0.10 - 6.99	1.48	0.01 - 1.15	0.34	0.03 – 2.00	0.56	0.08 - 1.09	0.40	0.09 - 3.11	0.65	0.02 - 0.16	0.07	0.00 - 3.01	0.29	0-5 mg/L

* Values taken from Water Quality for Agriculture, FAO (Ayers and Westcot, 1985) as no information is available in DWAF guidelines for these constituents.

Var.: Variation

The variations of some physico-chemical parameters of groundwater and pond water are considered. These included:

5.3.5.1.1 pH

pH is the most common measure of the acidity/alkalinity balance in a solution. It is a measure of the availability in solution of hydrogen ions (H^+) also known as "protons". In formal terms, pH is defined as the negative logarithm (to base 10) of the hydrogen ions activity (in moles/Litre). pH values commonly fall in the range between 0 and 14 (Younger, 2007).

All the pH values of borehole water met the target range for South African irrigation water guidelines as included in 6.5-8.4 (Figure 5.6a). Most of the pH values of pond water met also this target range (Figure 5.6b). However, some pond water samples are alkaline as their values are above 8.4.

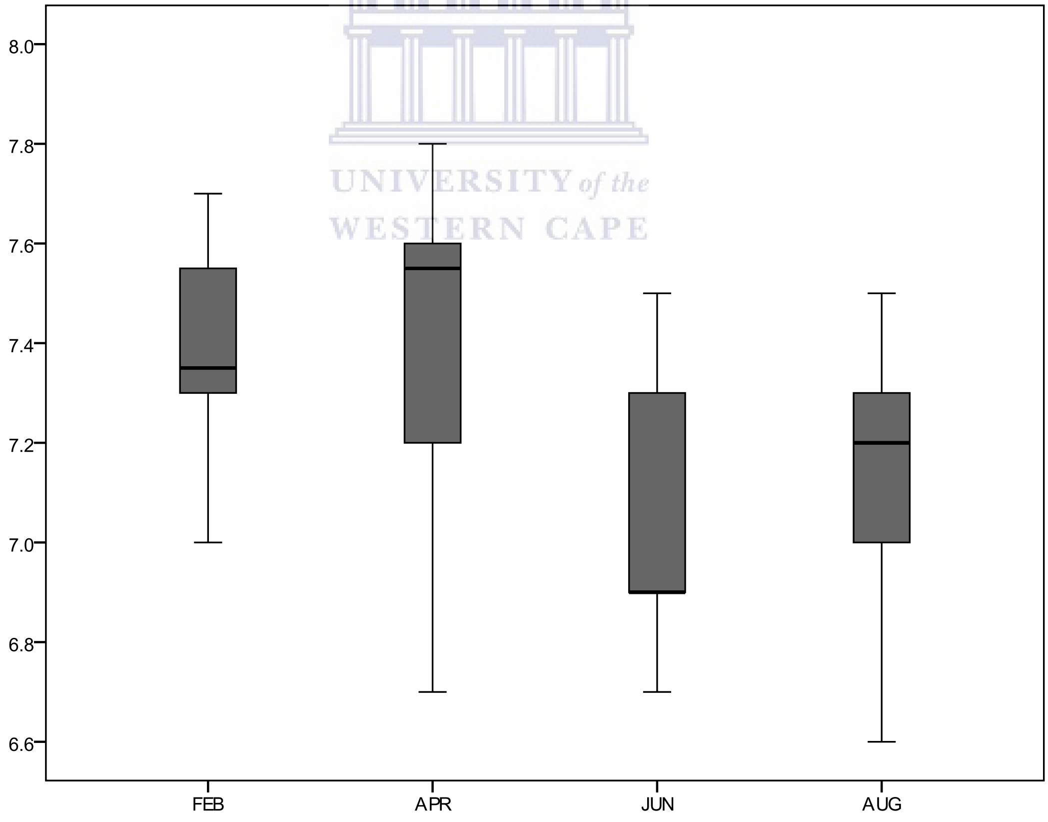


Fig 5.6a: Variation of pH values during the sampling period (BH)

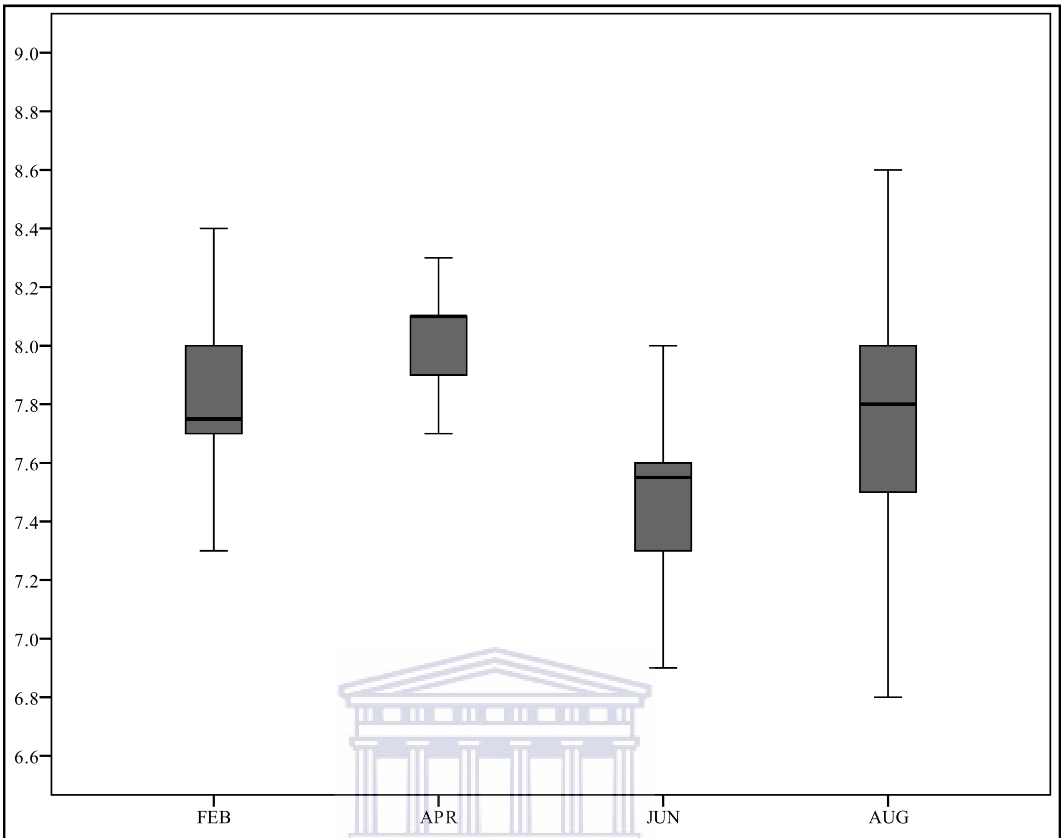


Fig 5.6b: Variation of pH values during the sampling period (Pond)

5.3.5.1.2 Electrical Conductivity (EC)

The electrical conductivity (EC) or specific conductance is the measure of the ability of a given water sample to conduct electricity, and it provides a proxy measure of the total quantity of ions in solution. It is expressed in unit such as milliSiemens per meter (mS/m) or microSiemens per centimeter (µS/cm) (Schwartz and Zhang, 2003).

Over the course of the survey, the ranges of the EC values (mS/m) of the borehole and pond waters did not meet the target range for South African irrigation water guidelines as the values were above the recommended range which is 0-40 mS/m. Variations of the EC values during the survey are shown in Figures 5.7a and 5.7b.

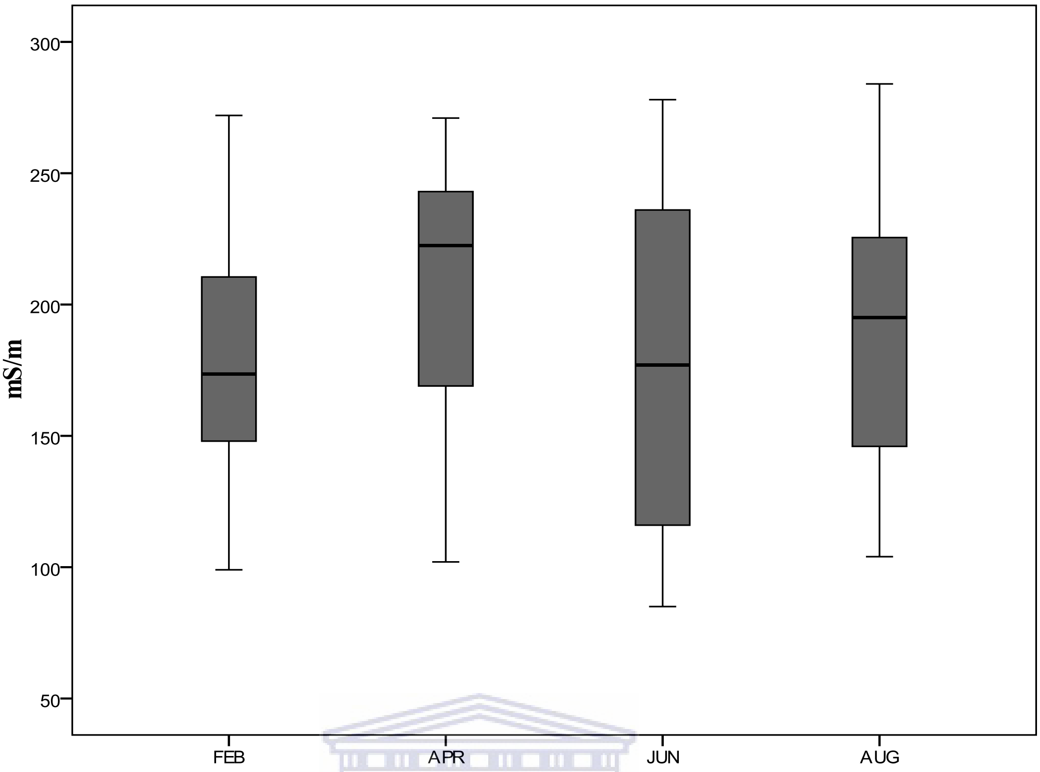


Fig 5.7a: Variation of EC values during the sampling period (BH)

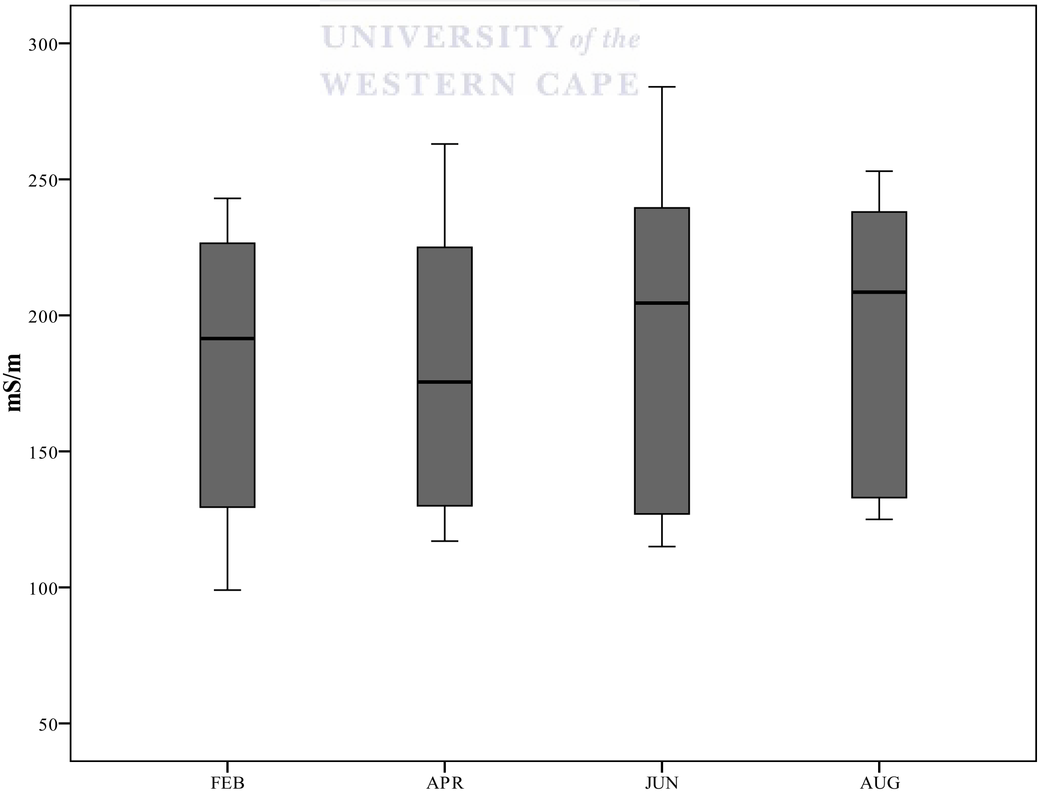


Fig 5.7b: Variation of EC values during the sampling period (Pond)

5.3.5.1.3 Total Dissolved Salts (TDS)

The total dissolved salts (TDS) content is a measure of the quantity of various dissolved minerals in water, and it is expressed in milligram per litre (mg/L). Irrigation with water containing salt induces salt into the soil profile. When no or little leaching of salt takes place from the soil profile, salt accumulates and a saline soil is formed (DWAF Irrigation water guidelines, 1996).

As directly proportional to the electrical conductivity of water, the TDS concentration is estimated by multiplying the value of the electrical conductivity expressed in mS/m of the water by some factor in the range between 5.5 and 7.5 (DWAF Irrigation water guidelines, 1996). An average value of 6.5 has been used for the factor as suggested in the South African Irrigation Water guidelines. The following formula has been used to estimate the TDS concentration in the collected water samples.

$TDS(mg/L) = 6.5 \times EC$; Where EC is expressed in mS/m.

As shown in figures 5.8a and 5.8b, most of the TDS concentration values of both borehole and pond water was greater than 1 000 mg/L. The maximum values of the TDS concentrations were less than 10 000 mg/L. In Tables 5.5a and 5.5b in Appendix 3, all arithmetic mean values of the TDS concentrations fell in the range 1 000-10 000 mg/L. That indicates that in the study area both borehole and pond water were mostly brackish regarding the water classification based on the TDS content (Table 3.1 in Chapter 3). However, some borehole and pond water were fresh in places in the study area as their TDS values were less than 1 000 mg/L.

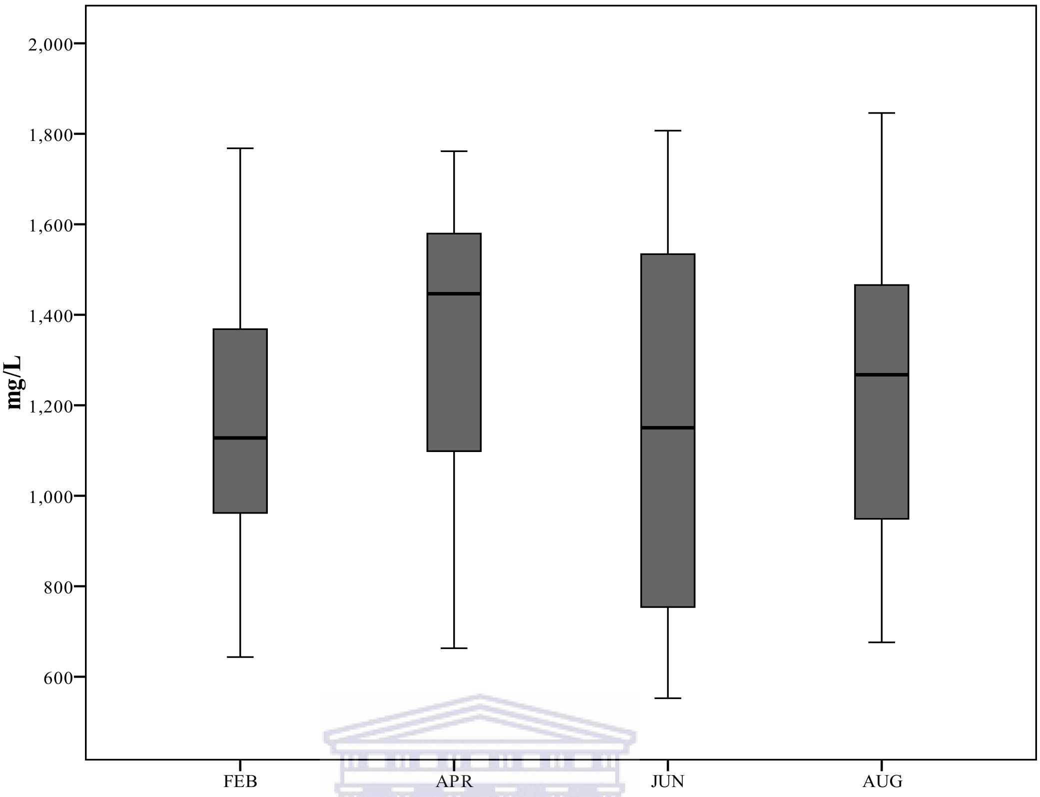


Fig 5.8a: Variation of TDS values during the sampling period (BH)

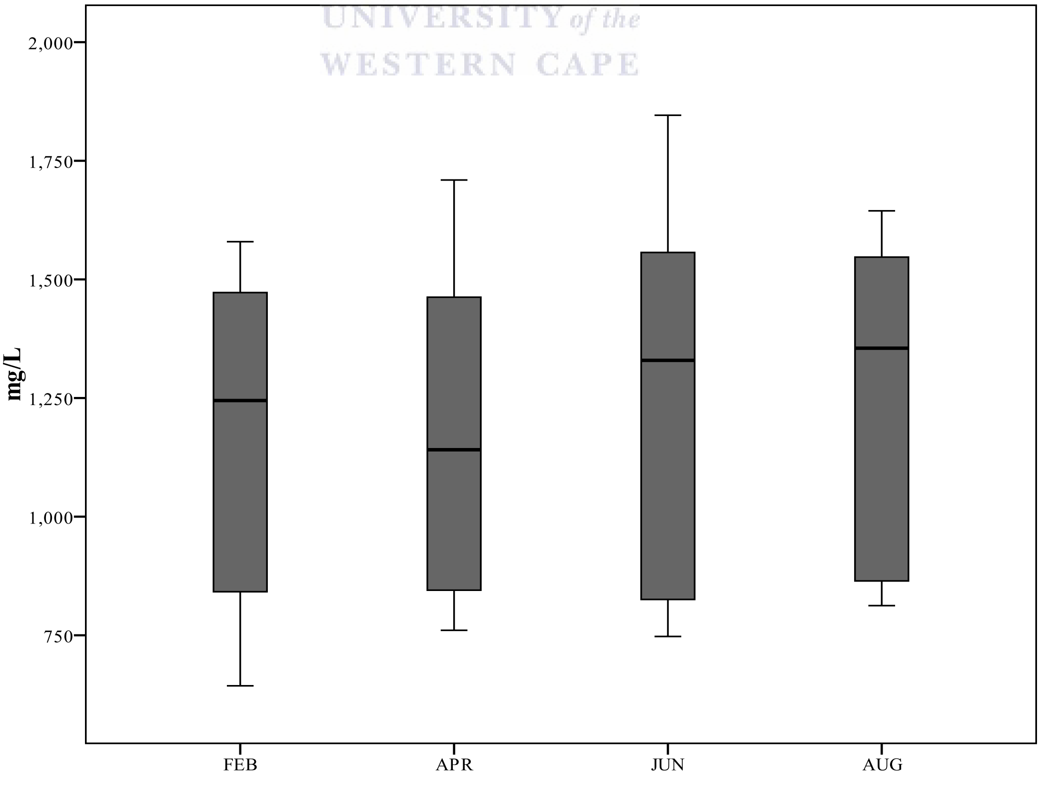


Fig 5.8b: Variation of TDS values during the sampling period (Pond)

5.3.5.1.4 Magnesium (Mg^{2+})

The maximum values of magnesium concentrations expressed in milliequivalent per liter (meq/L) of both borehole and pond waters collected during the sampling period did not exceed the recommended value set by the FAO guidelines (Ayers and Westcot, 1985) which is 5 meq/L (Table 5.6).

5.3.5.1.5 Calcium (Ca^{2+})

The maximum values of calcium concentrations expressed in milliequivalent per liter (meq/L) of both borehole and pond waters collected during the sampling period did not exceed the recommended value set by the FAO guidelines (Ayers and Westcot, 1985) which is 20 meq/L (Table 5.6).

5.3.5.1.6 Bicarbonate (HCO_3^-)

The maximum values of bicarbonate concentrations expressed in milliequivalent per liter (meq/L) of both borehole and pond waters collected during the sampling period did not exceed the recommended value in irrigation water set by the FAO guidelines (Ayers and Westcot, 1985) which is 10 meq/L (Table 5.6).

5.3.5.1.7 Sodium (Na^+)

According to the DWAF Irrigation water guidelines (1996), sodium is an alkali metal which reacts with water to form highly soluble positively charged sodium ions. In minute quantities, sodium is beneficial to the growth of some plants. At higher concentrations it is, however, toxic to many plants, especially woody plants. Sodium also has a potentially detrimental effect on soil physical conditions.

Over the course of the survey, most of the sodium concentration values for both borehole and pond waters were above the target value set by DWAF guidelines (1996) for irrigation waters which is 70 mg/L. Few water samples from borehole and pond had sodium concentration values less than 70 mg/L (Figures 5.9a and 5.9b).

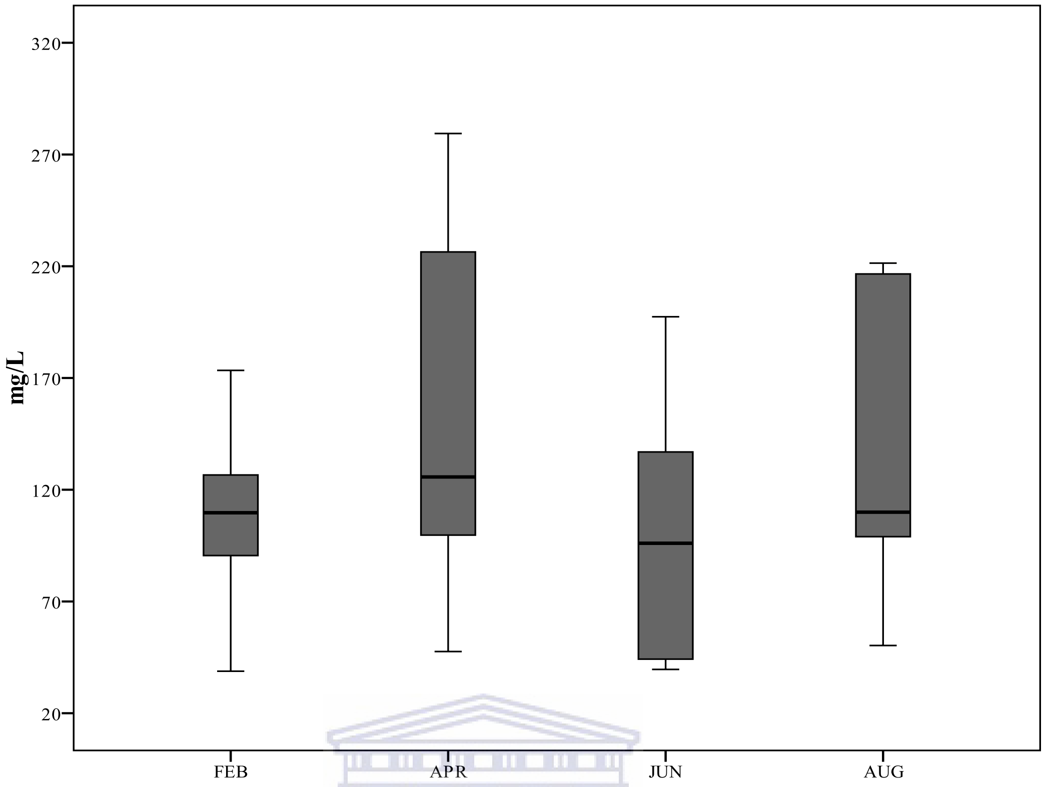


Fig 5.9a: Variation of Sodium concentrations during the sampling period (BH)

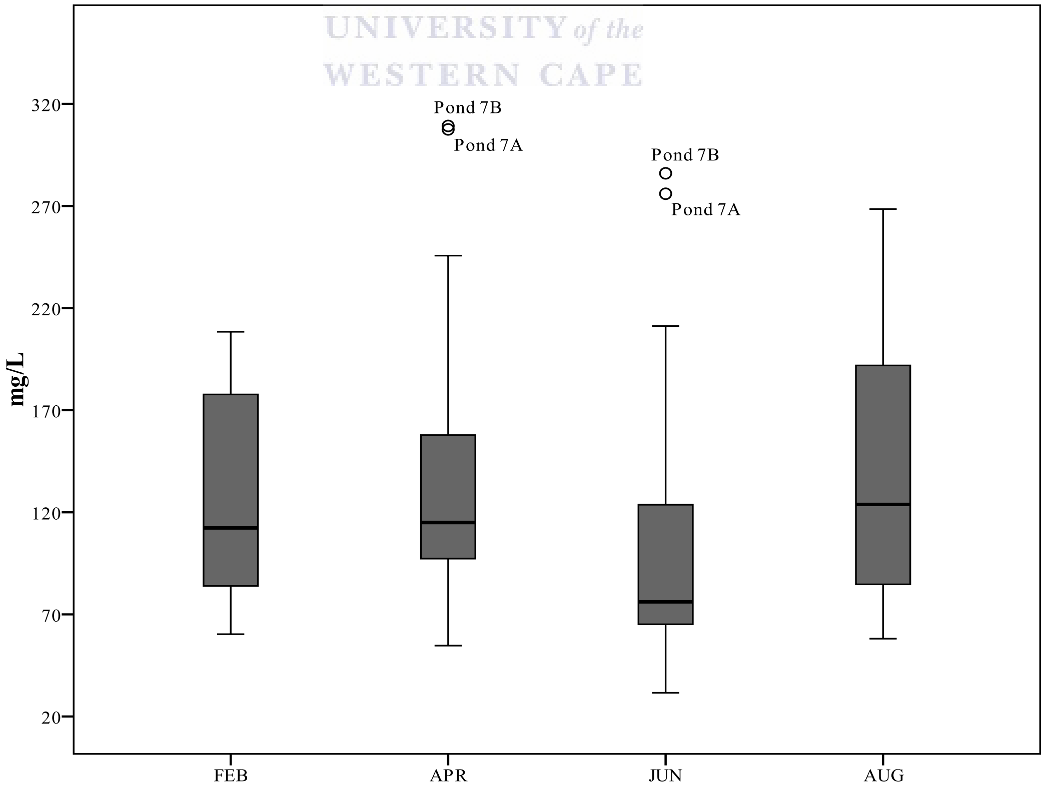


Fig 5.9b: Variation of Sodium concentrations during the sampling period (Pond)

5.3.5.1.8 Chloride (Cl^-)

According to the DWAF Irrigation water guidelines (1996), chloride is the anion of the element chlorine. Chloride is highly soluble in water and once in solution tends to accumulate. Chloride is an essential plant micronutrient, but unlikely it is, however, relatively toxic to most crops at higher concentration.

Over the course of the survey, most of the borehole samples had their chloride concentrations above the target value 100 mg/L set by DWAF guidelines (1996) for irrigation waters whereas all the chloride concentrations of the pond samples exceeded the target value (Figures 5.10a and 5.10b).

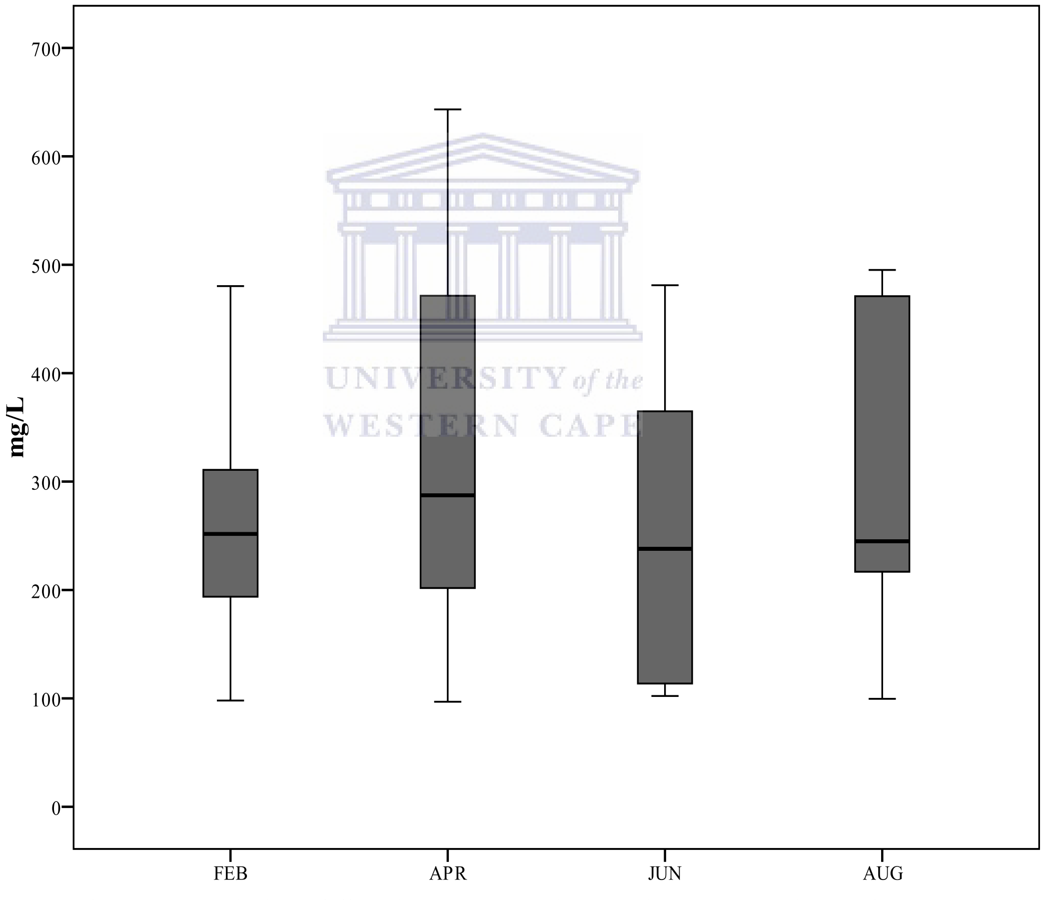


Fig 5.10a: Variation of Chloride concentrations during the sampling period (BH)

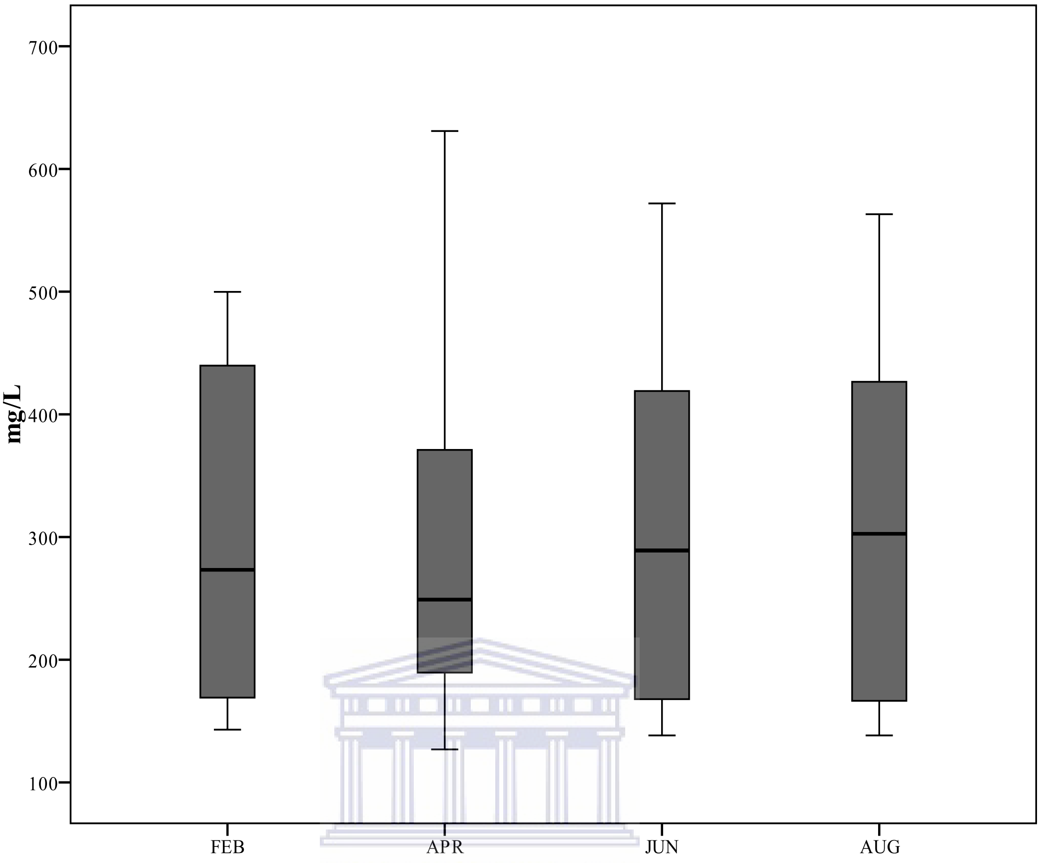


Fig 5.10b: Variation of Chloride concentrations during the sampling period (Pond)

5.3.5.1.9 Boron (B)

Boron is necessary in very small quantities for normal growth of all plants but it becomes toxic in larger concentrations (DWAF, 1996; Todd and Mays, 2005). Over the course of the survey, the concentrations of boron were low in both borehole and pond water. The maximum values of boron concentration for both borehole and pond waters did not exceed the target value 0.5 mg/L set by DWAF guidelines (1996) for irrigation waters. Patterns in concentrations of boron over the course of the survey are shown in Figures 5.11a and 5.11b.

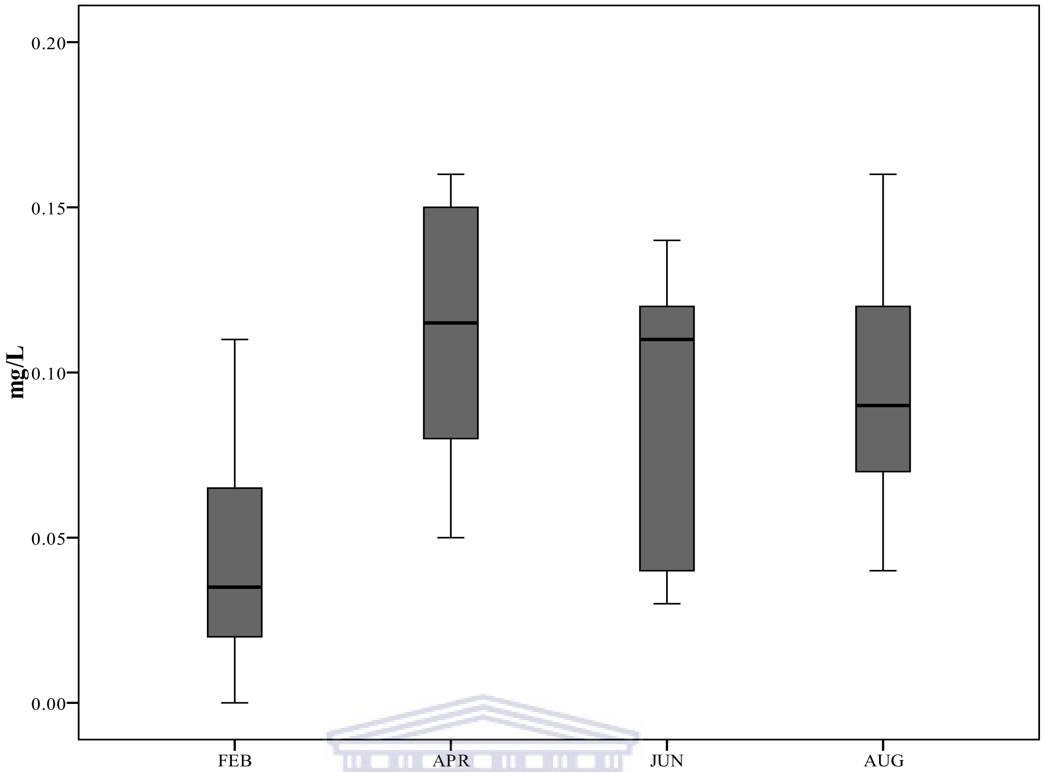


Fig 5.11a: Variation of Boron concentrations during the sampling period (BH)

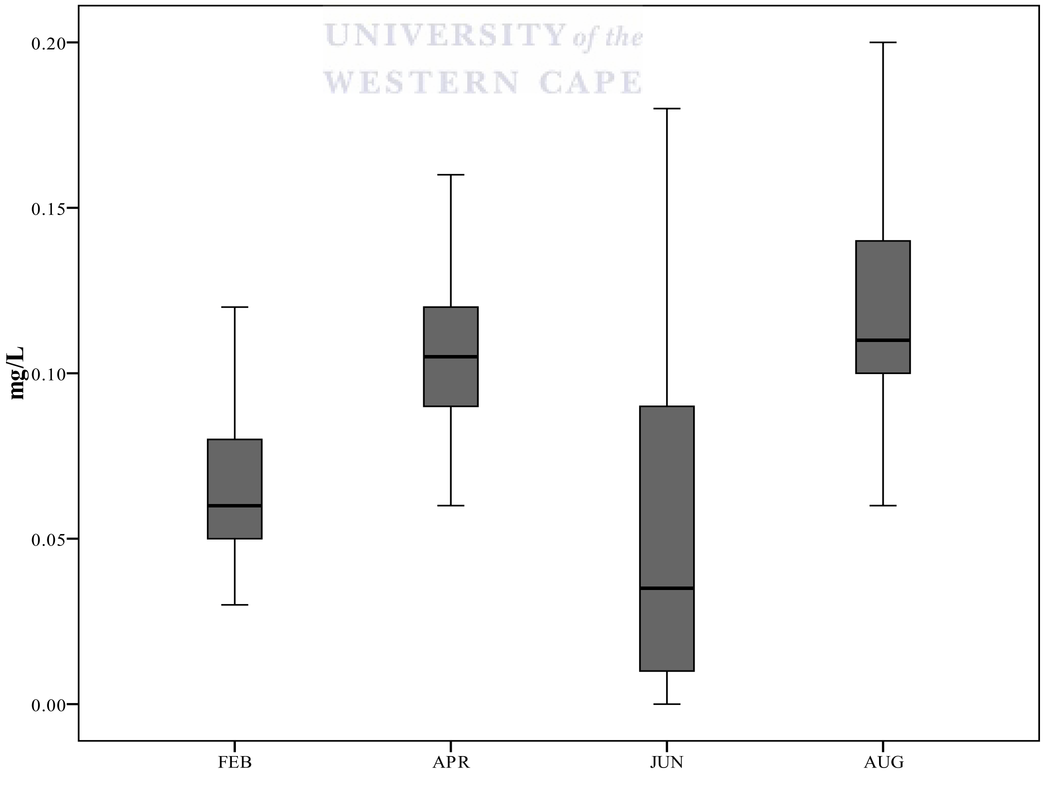


Fig 5.11b: Variation of Boron concentrations during the sampling period (Pond)

5.3.5.1.10 Potassium (K^+)

The potassium concentration values (in mg/L) over the course of the survey were largely out of the usual range of potassium concentration in irrigation water set by the FAO guidelines (Ayers and Westcot, 1985) which is 0-2 mg/L. Patterns in concentrations of potassium over the course of the survey are shown in Figures 5.12a and 5.12b.

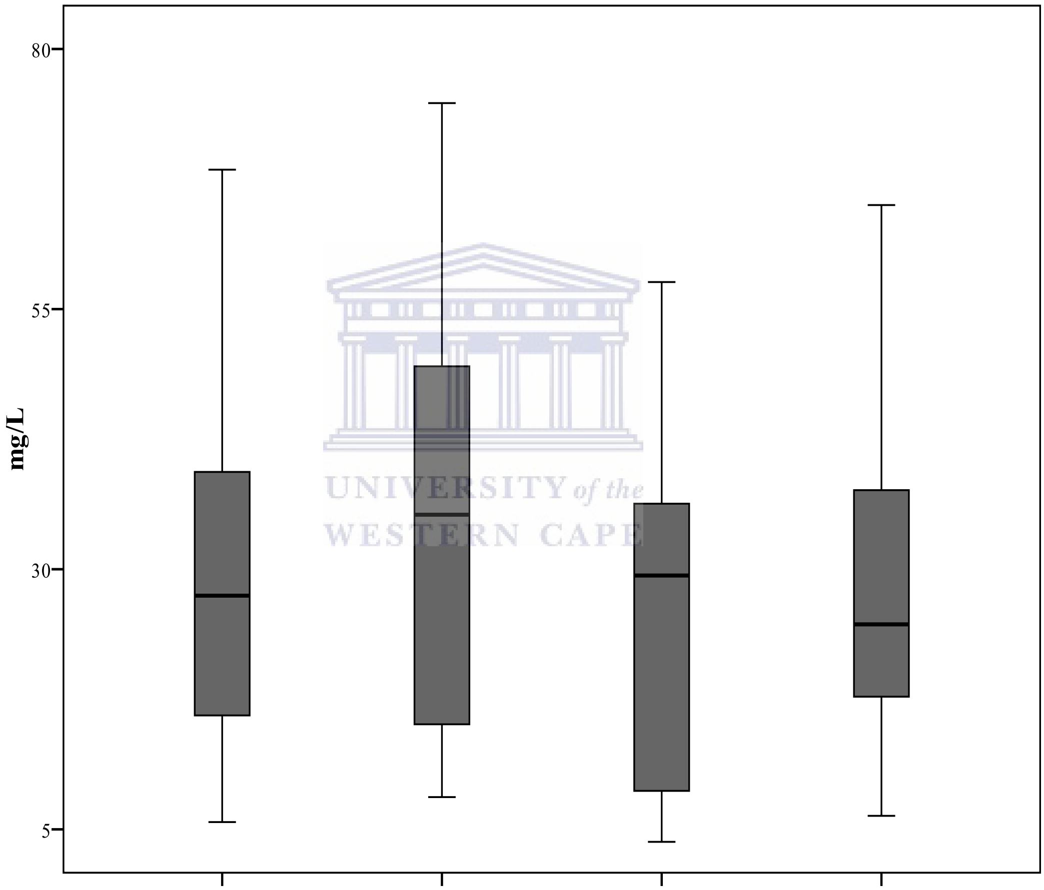


Fig 5.12a: Variation of Potassium concentrations during the sampling period (BH)

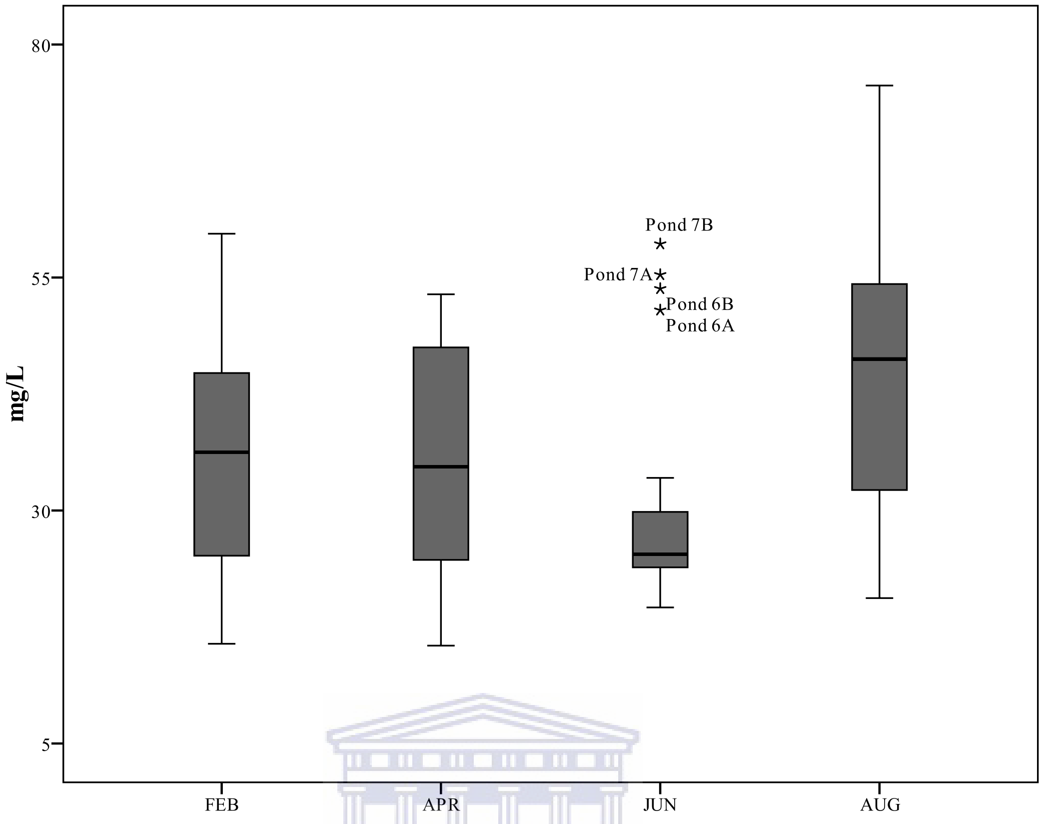


Fig 5.12b: Variation of Potassium concentrations during the sampling period (Pond)

5.3.5.1.11 Sulfate (SO_4^{2-})

The values of sulfate concentrations expressed in milliequivalent per liter (meq/L) of the waters collected during the sampling period did not exceed the recommended value set by the FAO guidelines (Ayers and Westcot, 1985) which is 20 meq/L (Table 5.6).

5.3.5.1.12 Nitrate (NO_3^-)

According to DWAF guidelines (1996), nitrate is a form of the inorganic nitrogen in water. It is the most stable form and occurs predominantly in irrigation water. Being an anion, nitrate is very weakly absorbed by the soil exchange complex and its movement in the soil is considered to be unaffected by exchange reactions. Nitrate and the other forms of nitrogen such as nitrite, ammonia and ammonium are ones of the essential macro plant nutrients. However, they are primarily concern in irrigation water because of their stimulatory effect on plant growth when applied in excess of plant requirements, and their potential to leach and contaminate ground water sources.

Nitrate was fairly distributed in groundwater across the study area over the course of the survey with its arithmetic mean concentration values less than the target value recommended by DWAF guidelines which is 5 mg/L (Table 5.6). However, the arithmetic mean concentration values of nitrate of the pond water were above this recommended value throughout the year (Table 5.6). It is observed that the concentration values of nitrate in the pond water were greater than the concentration values of nitrate in borehole water. The high level of nitrate concentration in the pond water could be related to the fertilizers applied over the cultivated area that go to the ponds through the drainage system by the return flow water. Patterns in concentrations of nitrate over the course of the survey are shown in Figures 5.13a and 5.13b.

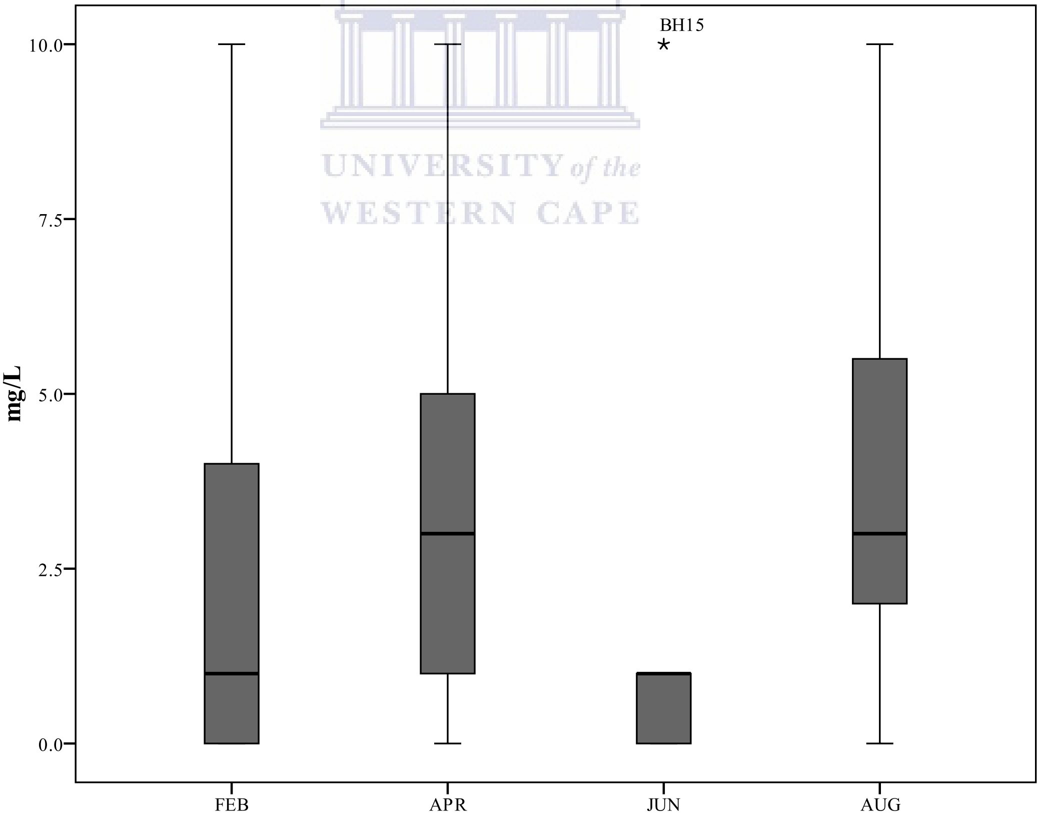


Fig 5.13a: Variation of Nitrate concentrations during the sampling period (BH)

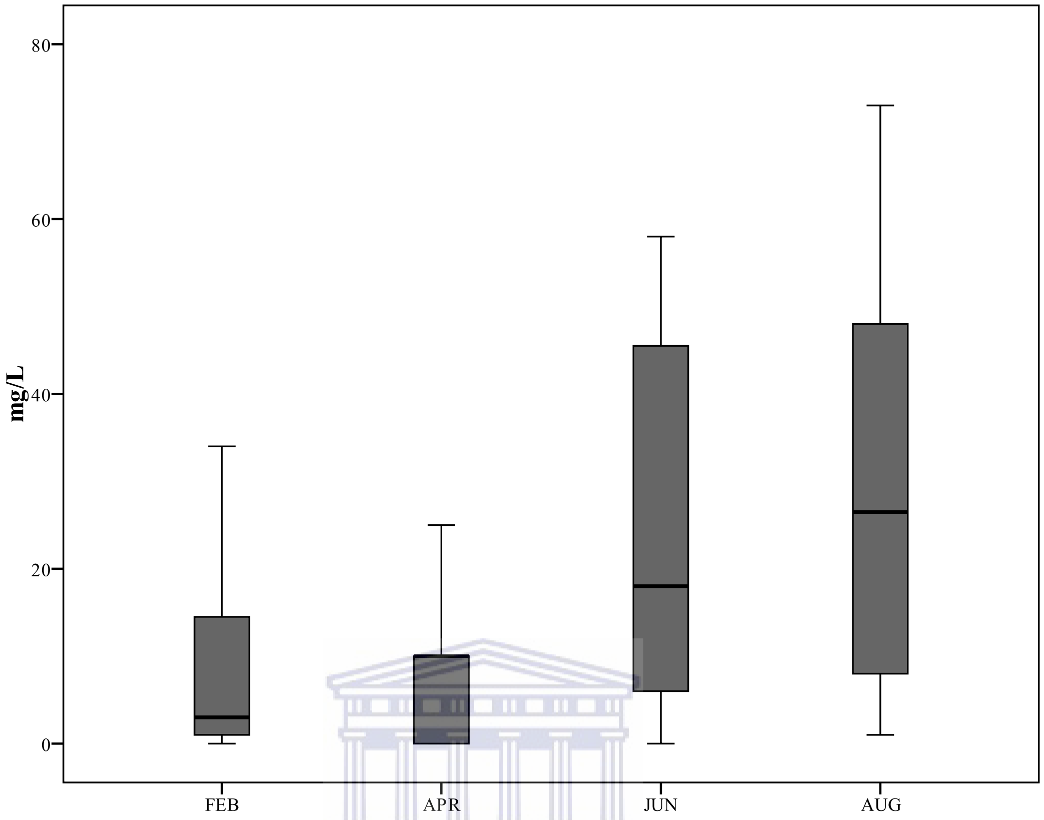


Fig 5.13b: Variation of Nitrate concentrations during the sampling period (Pond)

5.3.5.1.13 Manganese (Mn^{2+})

According to the DWAF Irrigation water guidelines (1996), manganese is an essential plant nutrient. It appears to be required as an enzyme activator. Its concentration is highest in the reproductive parts of plants (seeds) and lowest in woody sections.

The maximum value of manganese concentration set by DWAF guidelines (1996) for irrigation waters is 0.02 mg/L. In the study area, the values of the manganese concentrations exceeded this target value in places for both borehole and pond waters. Manganese constituent appeared more in summer in the various waters (Figures 5.14a and 5.14b) than in winter.

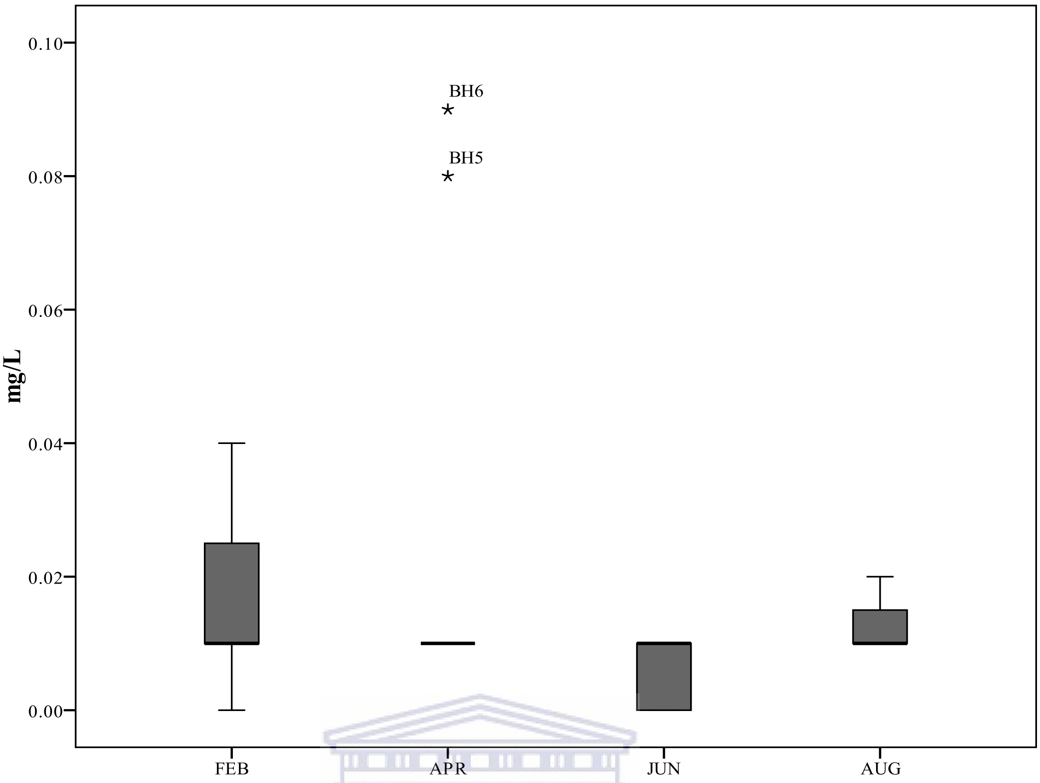


Fig 5.14a: Variation of Manganese concentrations during the sampling period (BH)

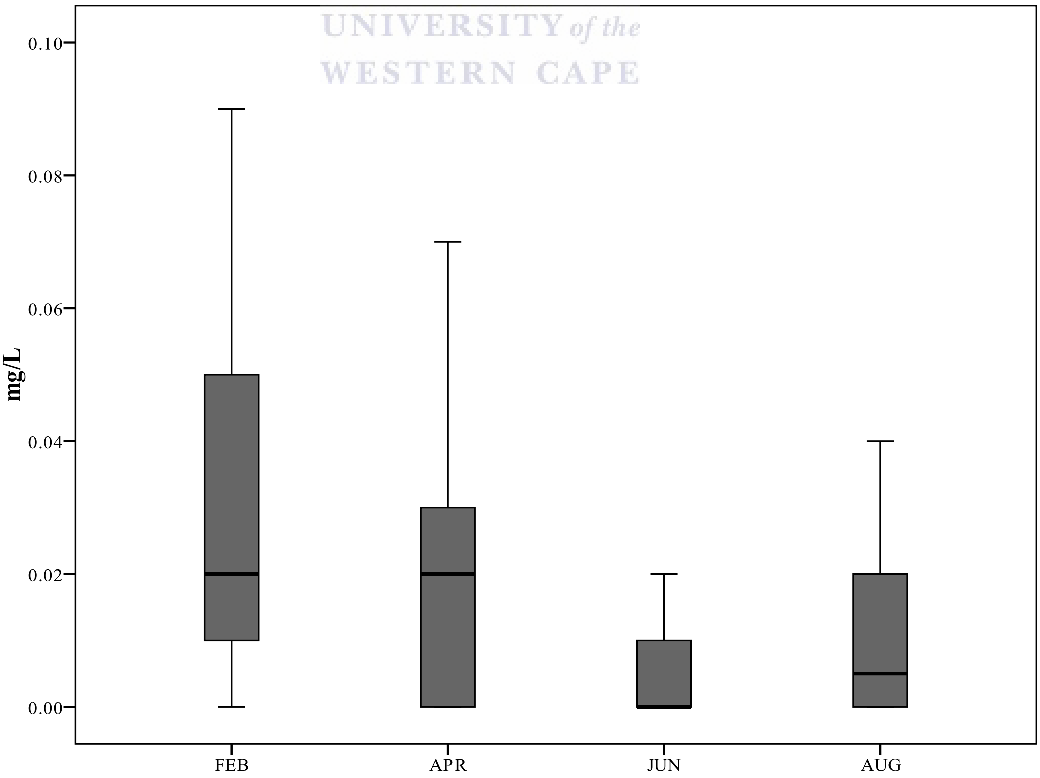


Fig 5.14b: Variation of Manganese concentrations during the sampling period (Pond)

5.3.5.1.14 Iron (Fe^{2+})

As shown in Figure 5.15a most of the borehole samples had the iron content below the target value set by DWAF for irrigation waters which is 5 mg/L, except in summer where samples from one borehole had its iron content greater than 5 mg/L. The values of the iron concentrations for the pond water met the target range for South African irrigation water guidelines which is 0-5 mg/L as all the pond samples had iron content that were below the target value (Figure 5.15b).
The high level of iron concentrations observed in groundwater could be related to the piping asset used to pump out water from the boreholes.

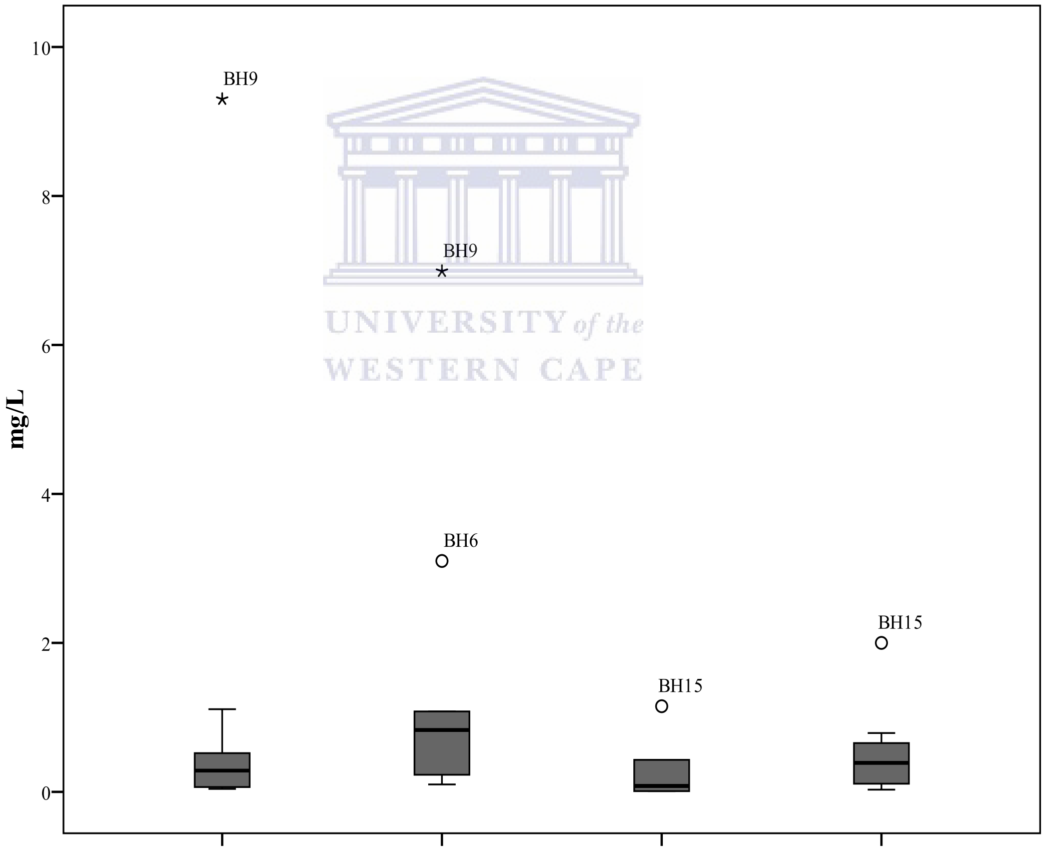


Fig 5.15a: Variation of Iron concentrations during the sampling period (BH)

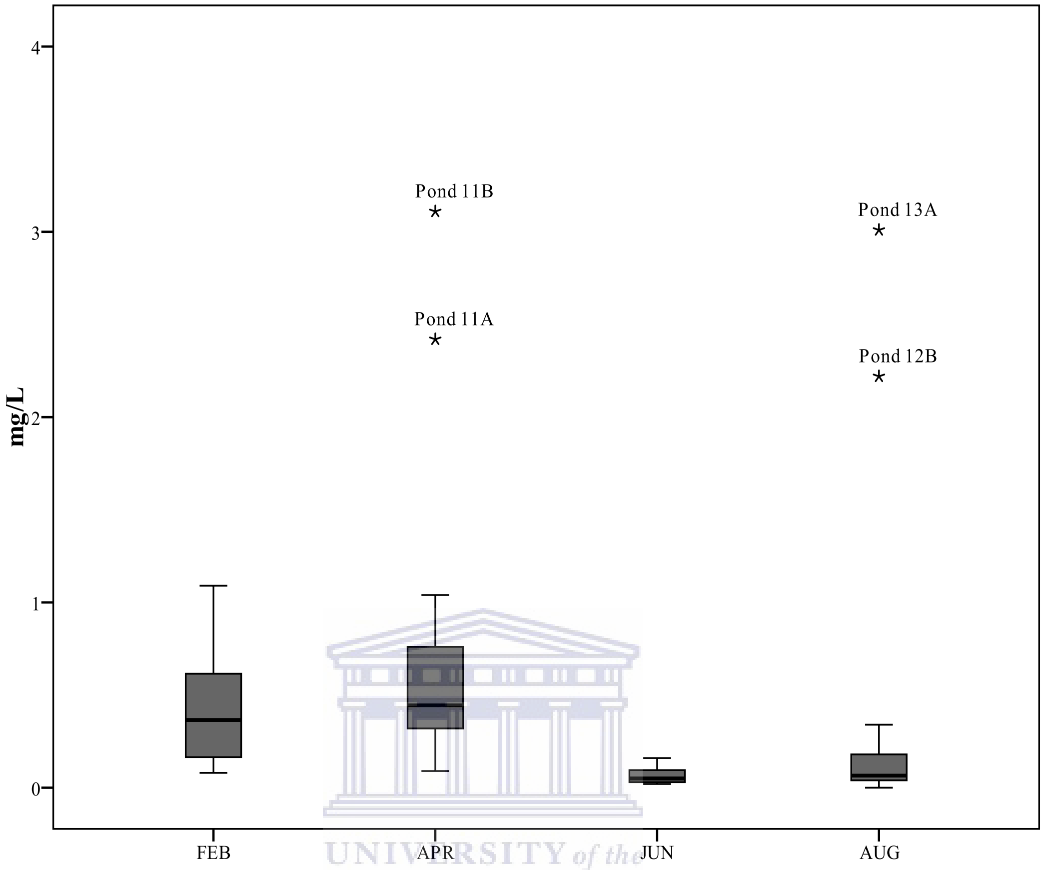


Fig 5.15b: Variation of Iron concentrations during the sampling period (Pond)

5.3.5.1.15 Temperature

In summer, the variations of the temperature were between 18.2-19.5°C and 18.7-25.6°C for borehole and pond water respectively. Whereas in winter, the range values were 16.4-18.4°C and 14.0-16.1°C for borehole and pond water respectively (Table 5.7). Since pond water is an open water body, its temperature is more influenced by the temperature variations induced by the ambient weather than the temperatures of groundwater. The groundwater temperature remained greater than the temperature of pond water in winter; this could be due to the geothermal gradient of the earth’s crust as groundwater temperature increases approximately 2.9°C for each 100 meters of depth (Todd and Mays, 2005).

5.3.5.2 Hydrogeochemical interpretation

Water and the geological formations through which water flows constitute a complex dynamic system in which any change of one part of the system is reflected in the others (Cogho et al., 1989). Large Tables of analytical data are usually difficult to interpret regarding the variations in water quality (Todd and Mays, 2005). Graphs are useful for this purpose and several specialized types are in use. Amongst others, Stiff diagram and Piper diagram have been used in the section to assess the interactions between the various components that affect the quality of the water in the study area.

5.3.5.2.1 Stiff diagrams

Stiff diagrams of sea water, rain water, spring water and groundwater from other areas in Cape Flats region have been realized as well with those for the water sampled during the entire sampling campaign. The patterns of anions and cations of these aforementioned waters on Stiff diagram are depicted in Figures 5.16a to 5.19.

As Stiff diagrams allow easy identification and relationship between the water samples, they show that:

- The borehole water samples and their related pond water samples have basically similar shapes throughout the entire sampling period, and the chemical constituents of the borehole water greatly influence the chemical composition of the pond water. This shows that the major source of water for filling up the ponds is indeed the borehole water in the study area.
- The shapes of the diagrams of all the collected samples clearly do not look like the shapes of the diagrams of the rain water and the sea water. This suggests that the borehole and the pond water are prone to other processes and sources of contamination could be affecting their chemical compositions.
- The borehole and the pond water samples are characterized either by Ca-Cl, Ca-HCO_3, Ca-SO_4 and Na-Cl chemical water types in the study area.

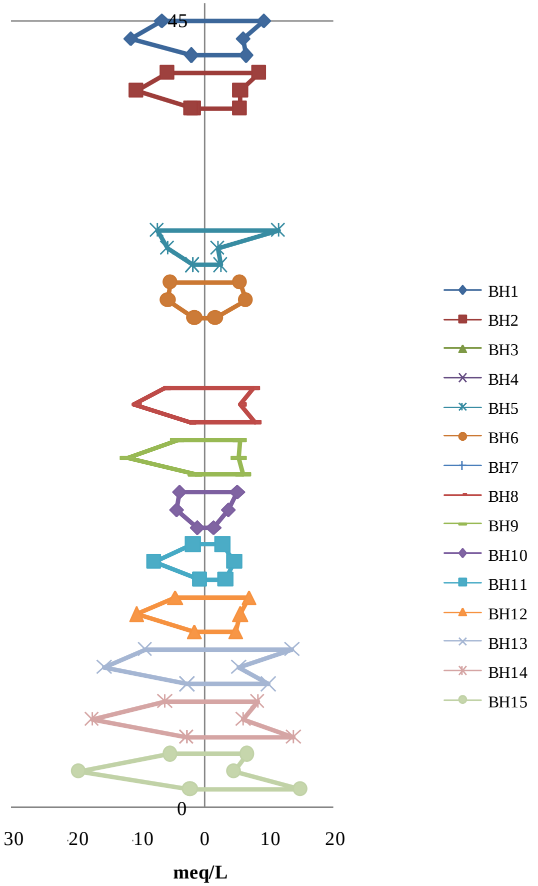


Fig 5.16a: Borehole stiff diagram (Feb)

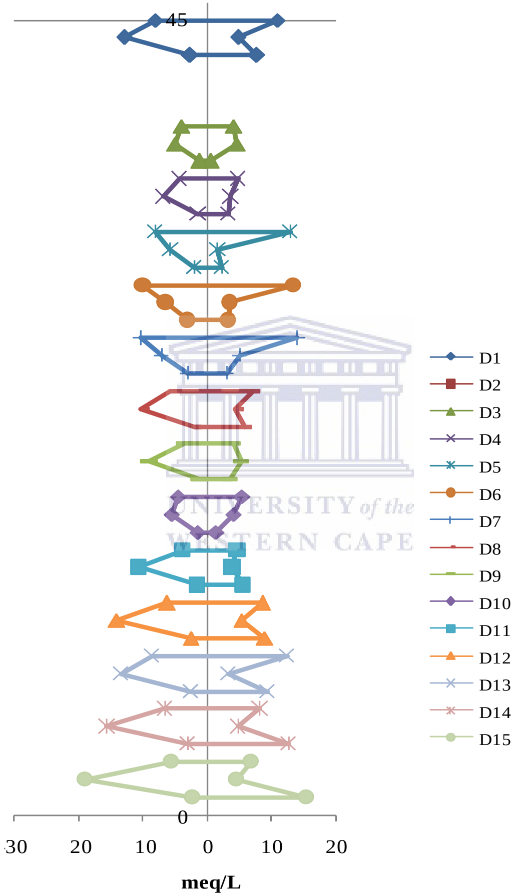


Fig 5.16b: Pond stiff diagram (Feb)

Particular waters

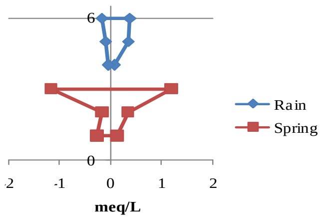


Fig 5.17: Stiff diagram of rain and spring water

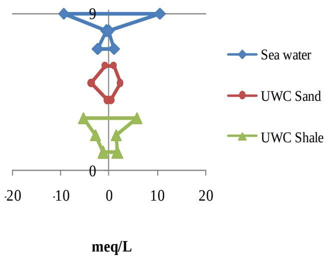


Fig 5.18: Stiff diagram of sea water and GW at UWC Site

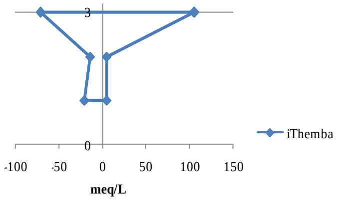
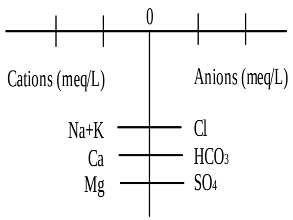


Fig 5.19: Stiff diagram of GW at iThemba

Layout of plotting axes



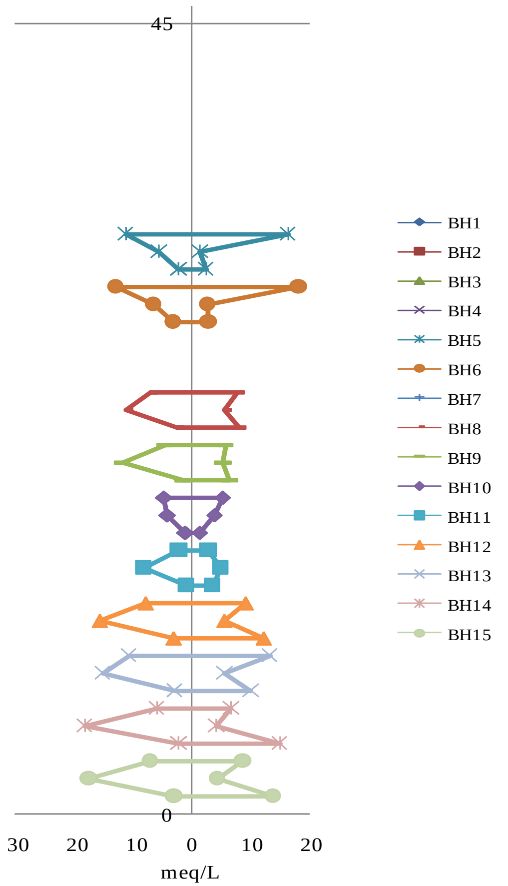


Fig 5.16c: Borehole stiff diagram (Apr)

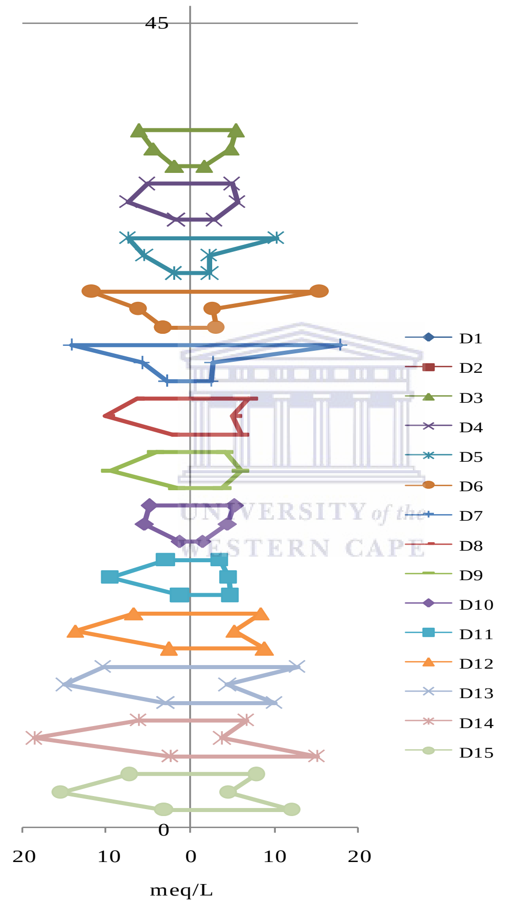


Fig 5.16d: Pond stiff diagram (Apr)

Particular waters

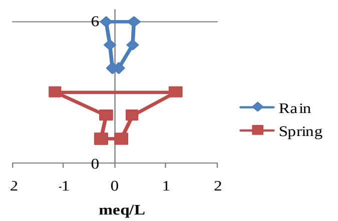


Fig 5.17: Stiff diagram of rain and spring water

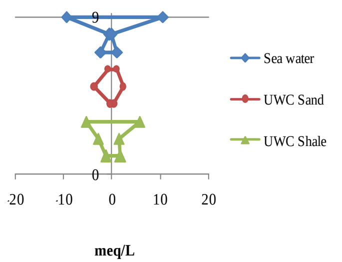


Fig 5.18: Stiff diagram of sea water and GW at UWC Site

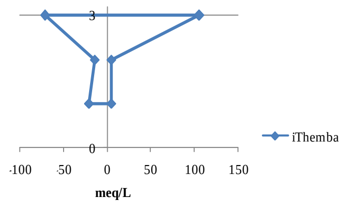
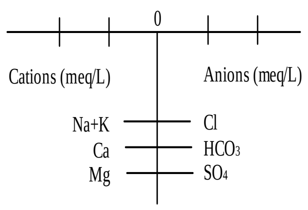


Fig 5.19: Stiff diagram of GW at iThemba

Layout of plotting axes



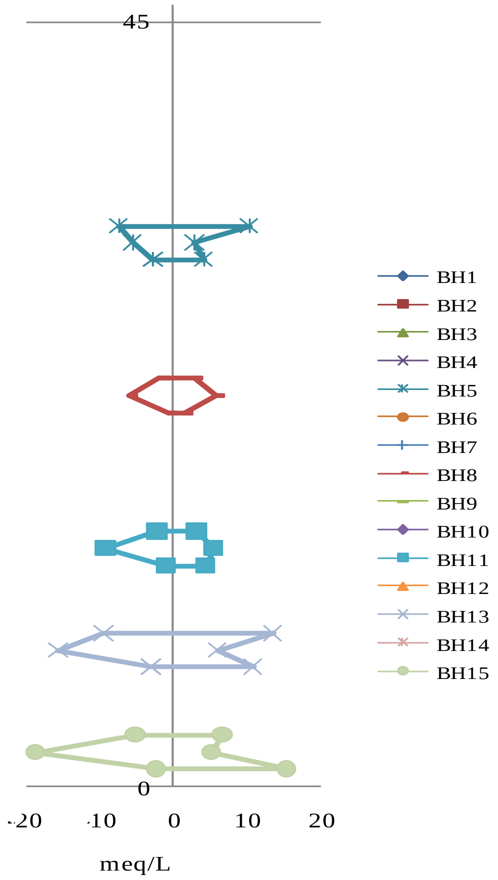


Fig 5.16e: Borehole stiff diagram (Jun)

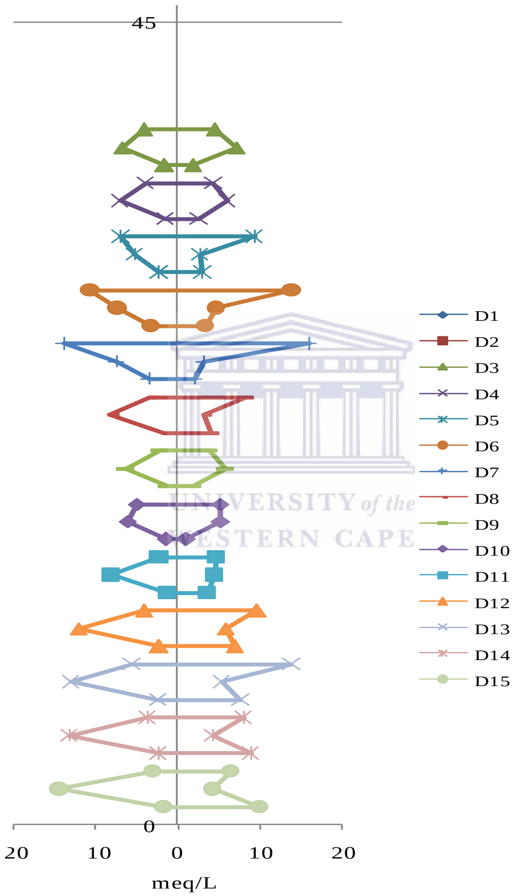


Fig 5.16f: Pond stiff diagram (Jun)

Particular waters

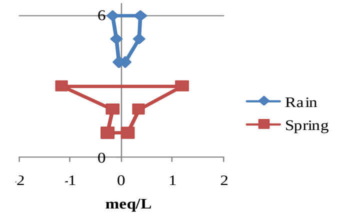


Fig 5.17: Stiff diagram of rain and spring water

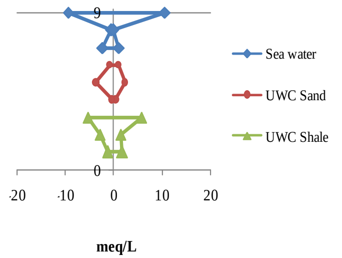


Fig 5.18: Stiff diagram of sea water and GW at UWC Site

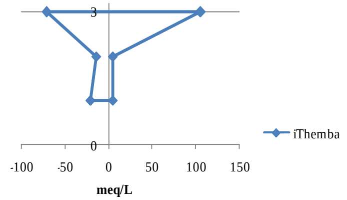
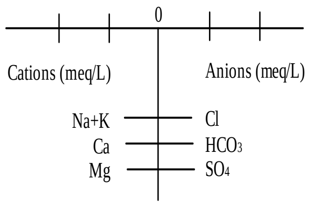


Fig 5.19: Stiff diagram of GW at iThemba

Layout of plotting axes



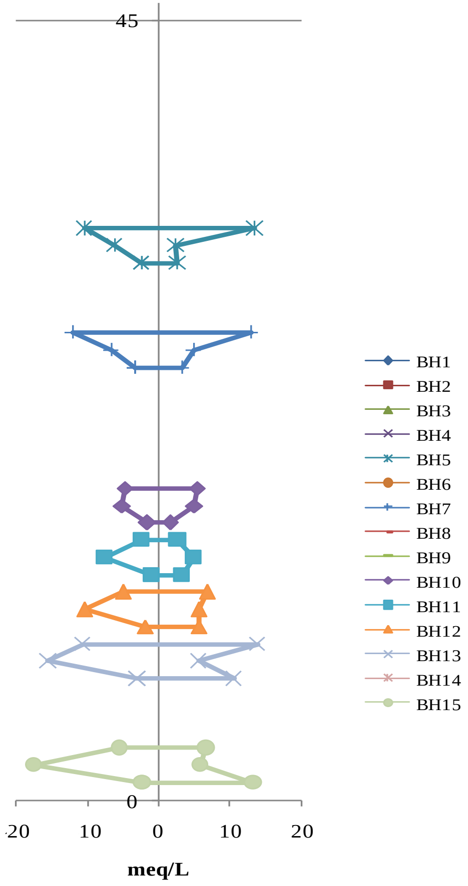


Fig 5.16g: BH stiff diagram (Aug)

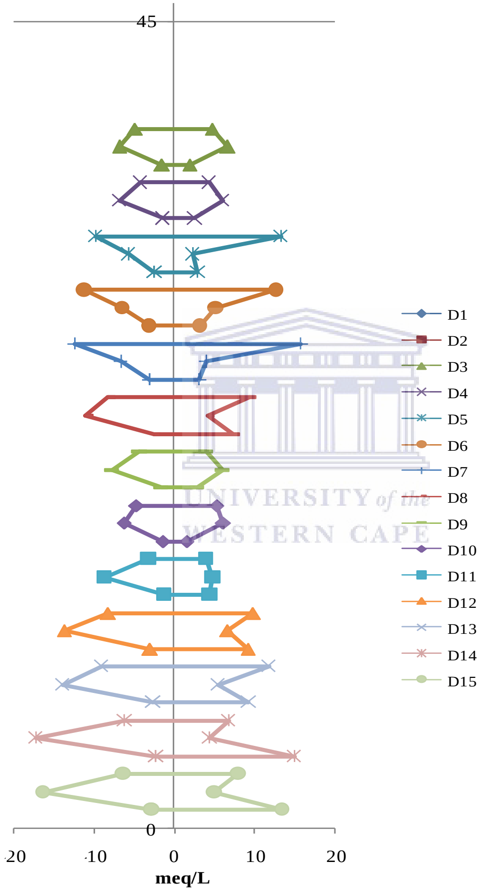


Fig 5.16h: Pond stiff diagram (Aug)

Particular waters

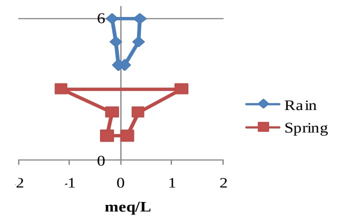


Fig 5.17: Stiff diagram of rain and spring water

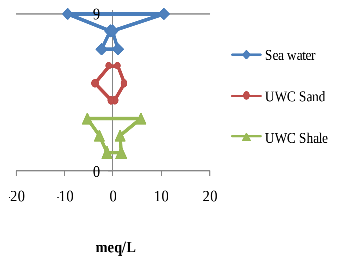


Fig 5.18: Stiff diagram of sea water and GW at UWC Site

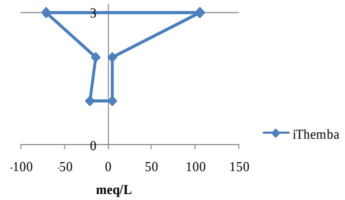
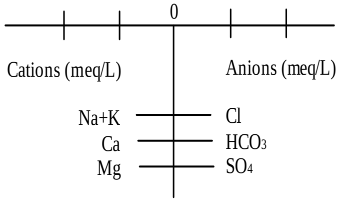


Fig 5.19: Stiff diagram of GW at iThemba

Layout of plotting axes



5.3.5.2.2 Piper diagrams

The water samples collected during the entire sampling period, rain water, sea water, spring water and groundwater from other places on the Cape Flats have been plotted on the Piper diagrams. Patterns in concentrations of cation and anion on the Piper diagrams of these aforementioned waters are shown in Figures 5.20a and 5.20b, and these findings might be drawn:

- Both the collected borehole and pond water data fell in the upper part of the diamond field of the Piper diagram. This suggests that the waters are prone to the ion exchange phenomena and are from mixture origin.
- Regarding the concept of hydrochemical facies developed to describe cation and anion concentrations based on subdivisions of the Piper diagram (Freeze and Cherry, 1979), groundwater is characterized either by Ca-Cl, Ca-HCO_3, Ca-SO_4 and Na-Cl chemical types in the study area. Some of these hydrochemical facies denote the influence of the dissolution of calcite, halite and gypsum, and the oxidation of pyrite and other sulfide minerals (Younger, 2007).
- Adelana et al. (2010) reported that the high salinity observed in groundwater in iThemba site may be due to the response to long-term pumping or the presence of a historic buried river channel near the wells. The groundwater samples from Philippi, whose plots were close to the plots of water samples from iThemba, might be as well subjected to the long-term pumping of the boreholes in the study area as farming activities have been established in Philippi since the 19th century.

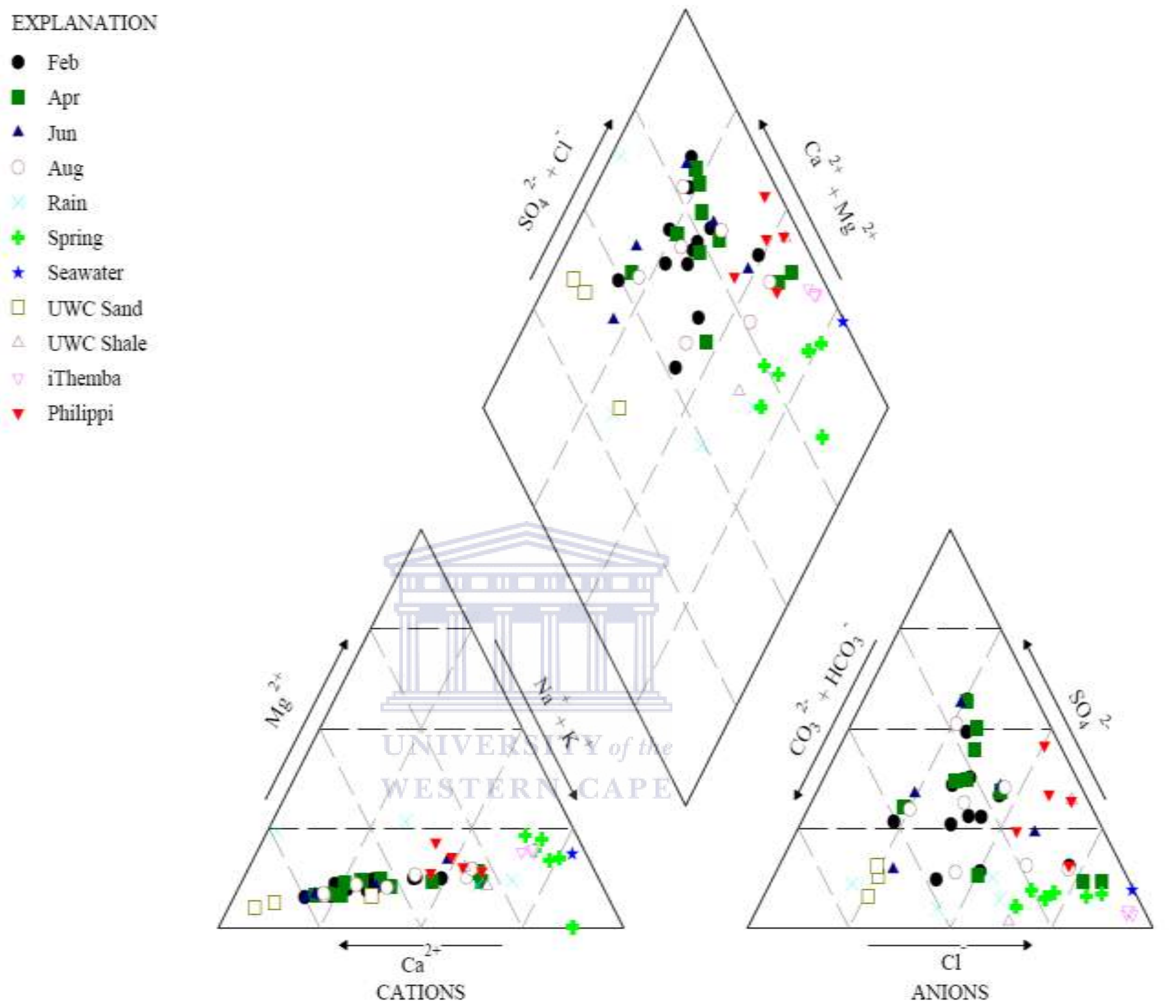


Fig 5.20a: Plot of BH water samples and water samples from other places of the Cape Flats region

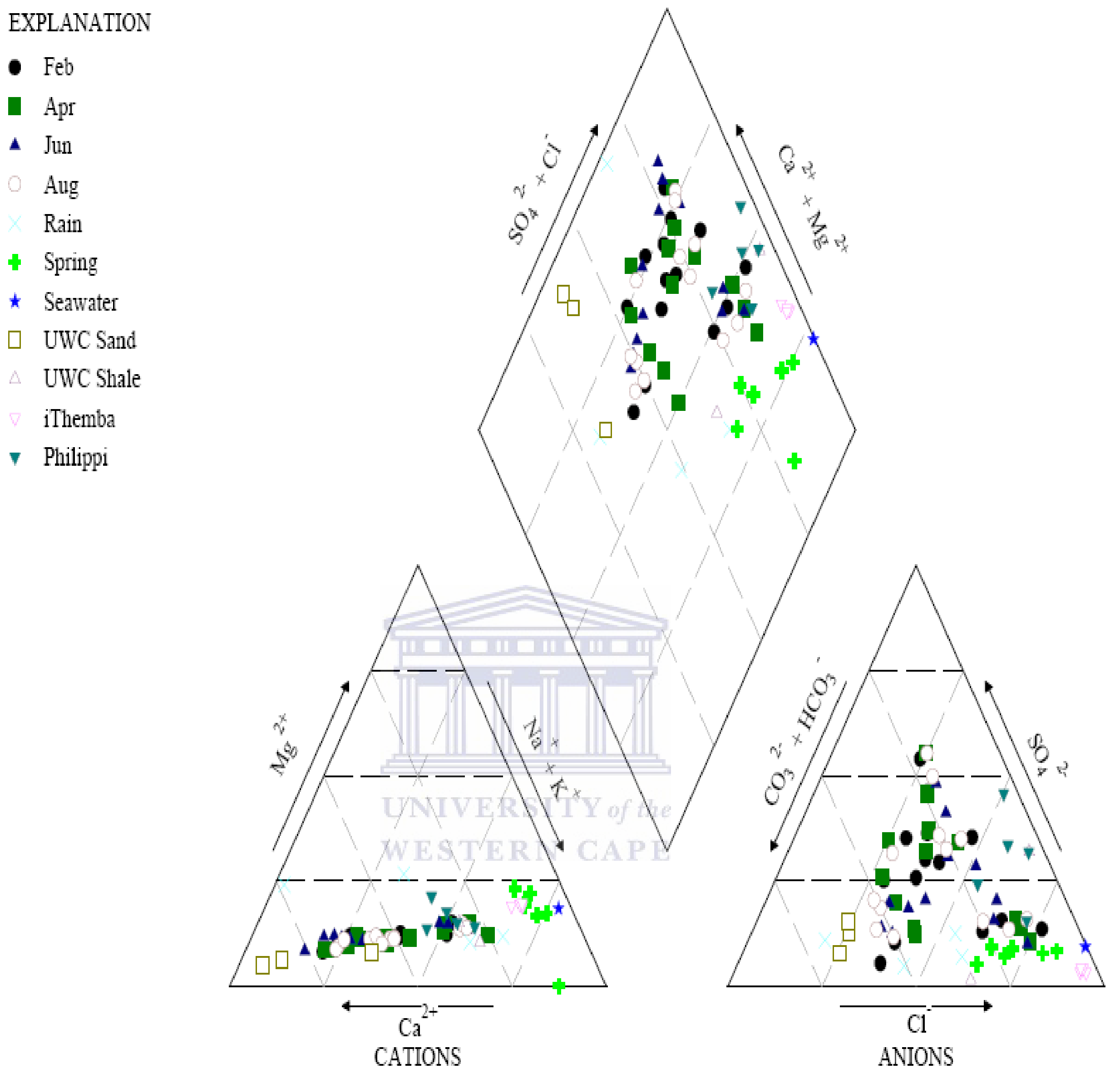


Fig 5.20b: Plot of pond water samples and water samples from other places of the Cape Flats region

5.4 Suitability for irrigation use

The water quality evaluation was carried out to determine its suitability for agricultural purposes as it is the main water use in the study area. The suitability of water for irrigation is contingent on the effects on the mineral constituents of the water on both the plant and the soil (Todd and Mays, 2005). They can limit growth of plants physically by restricting the taking up of water through modification of osmotic processes. Also salts may damage plant growth chemically by the effects of toxic substances upon metabolic processes (Khodapanah et al., 2009). Parameters such as electrical conductivity (EC) and sodium adsorption ratio (SAR) (Todd and Mays, 2005; Khodapanah et al., 2009), and the standard US salinity diagram developed by Richards (1954) will be used to assess the suitability of water for irrigation purposes in the study area.

5.4.1 Salinity Hazard

Excess salt increases the osmotic pressure of the soil solution that can result in a physiological drought condition. Even though the field appears to have plenty of moisture, the plants in the affected regions often wilt because insufficient water is absorbed by the roots to replace that lost from transpiration (Khodapanah et al., 2009). The total soluble salt content of irrigation water generally is measured either by determining its electrical conductivity (EC) reported as milliSiemens per meter (mS/m) or by determining the actual total dissolved salt (TDS) content in milligram per liter (mg/L) (DWAF, 1996).

The electrical conductivity values ranged between 85 mS/m and 284 mS/m for borehole water and between 99 mS/m and 284 mS/m for pond water during the sampling period. Based on the US Salinity Laboratory classification (Figures 5.21a and 5.21b), the salinity hazard for water samples in the study area is classified as follows:

- High category: 68.2% and 66.7% of the borehole water samples in summer and in winter respectively fell in category C3.
- Very high category: 31.8% and 33.3% of the borehole water samples in summer and in winter respectively fell in category C4.

- High category: 70.4% and 56.0% of the pond water samples in summer and in winter respectively fell in category C3.
- Very high category: 29.6% and 44.0% of the pond water samples in summer and in winter respectively fell in category C4.

During the entire sampling period, most of the borehole water samples belonged to the high salinity hazard category (C3) and a few samples belonged to the very high salinity hazard category (C4). For the pond water, most of the samples belonged to the high salinity hazard (C3) and the remaining fell in the very high salinity category (C4) in summer whereas the samples were more evenly between these two salinity categories during the winter. None of water samples had low or medium salinity contamination (categories C1 and C2).

Water samples that fell in the high salinity hazard class (C3) may have detrimental effects on sensitive crops and adverse effects on many plants. Such areas require careful management practices. However, very high salinity water (C4) is not suitable for irrigation under ordinary conditions but may be used for salt tolerant plants on permeable soils with special management practices (Kirchner, 1995; Khodapanah et al., 2009). As the vegetable crops grown in the study area are classified as sensitive and moderately sensitive to salt (DWAF Irrigation water guidelines, 1996), the water samples that fell in very high salinity category are not then at all suitable for the irrigation activities and specific management practices have to be taken in the zones where they occur.

5.4.2 Sodium or Alkali Hazard

Although sodium contributes directly to the total salinity, the main problem with a high sodium concentration is its effect on the physical properties of soil. While a high salt content (high EC) in water leads to formation of saline soil; high sodium content, high Sodium Adsorption Ratio (SAR), leads to development of an alkaline soil (Khodapanah et al., 2009). Irrigation with sodium enriched water results in ion exchange reactions: uptake of Na^+ and release of Ca^{2+} and Mg^{2+}. This causes soil aggregates to disperse, reducing its permeability (Kirchner, 1995; Khodapanah et al., 2009). The sodium or alkali hazard in the use of water for irrigation is determined by the absolute and relative concentration of cations and is expressed as the sodium adsorption ratio (SAR).The following formula, in which ions in the equation were expressed in milliequivalent per liter, is used to calculate the SAR:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Mg^{2+} + Ca^{2+}}{2}}}$$

There is a significant relationship between SAR values of irrigation water and the extent to which sodium is absorbed by the soils. Continued use of water with a high SAR value leads to a breakdown in the physical structure of the soil caused by excessive amounts of colloidally absorbed sodium. This breakdown results in the dispersion of soil clay that causes the soil to become hard and compact when dry and increasingly impervious to water penetration due to dispersion and swelling when wet. Fine-textured soils, those high in clay, are especially subject to this action (Cogho et al., 1989; Kirchner, 1995; Khodapanah et al., 2009).

In this survey, the adjusted SAR values (adj. SAR) determined by the commercial laboratory Bemlab Ltd have been used as the SAR. The adj. SAR values, in the study area, range from between 1.31-6.35 and 1.06-7.75 for borehole waters and pond waters respectively. The adj.SAR values plotted on the US salinity diagram as alkalinity hazard showed that alkali or sodium hazard for water samples in the study area is classified as follows:

- Low category: 81.8% and 66.7% of the borehole water samples in summer and in winter respectively fell in category S1.
- Medium category: 18.2% and 33.3% of the borehole water samples in summer and in winter respectively fell in category S2.
- Low category: 74.1% and 74.0% of the pond water samples in summer and in winter respectively fell in category S1.
- Medium category: 25.9% and 26.0% of the pond water samples in summer and winter respectively fell in category S2.

5.4.3 Water Classification

US salinity diagram developed by Richards (1954) was used in order to classify the borehole and pond water samples for irrigation uses in the study area. In the US salinity diagram, the electrical conductivity (EC) is taken as the salinity hazard and the sodium adsorption ratio (SAR) as the alkalinity hazard. The measured values of EC of water samples ranged between 85 mS/m to 284 mS/m and calculated adj. SAR values varied from 1.06 to 7.75 in the study area. The plot of data on the US salinity diagram shows that the water samples are found mostly confined in four classes of water type i.e. C3-S1, C3-S2 and C4-S1 and C4-S2 (Figures 5.21a and 5.21b). The specificities of these classes (Kirchner, 1995) are as follows:

- Water of C3-S1 class should only be used on soils which can be leached easy and salinity control must be practiced at all times (Philippi situation).
- Water of C3-S2 class should only be used on those soils which have good drainage and only plants having a good salt tolerance should be grown.
- Water of C4-S1 class is generally considered to be poor quality for irrigation but it may be used if all other conditions are favorable such as adequate drainage and application of additional good quality of water, and only crops of the highest salt tolerance should be grown.
- The very high salinity of water of C4-S2 class permits occasional use and only then under favorable soil and plant conditions. Only plants of high salt tolerance should be grown if water of this quality must be used.

As the vegetable crops grown in the study area are classified as sensitive and moderately sensitive to salt (DWAF Irrigation water guidelines, 1996); the water in the study area has to be then used with caution, and careful and special management practices have to be applied as well.

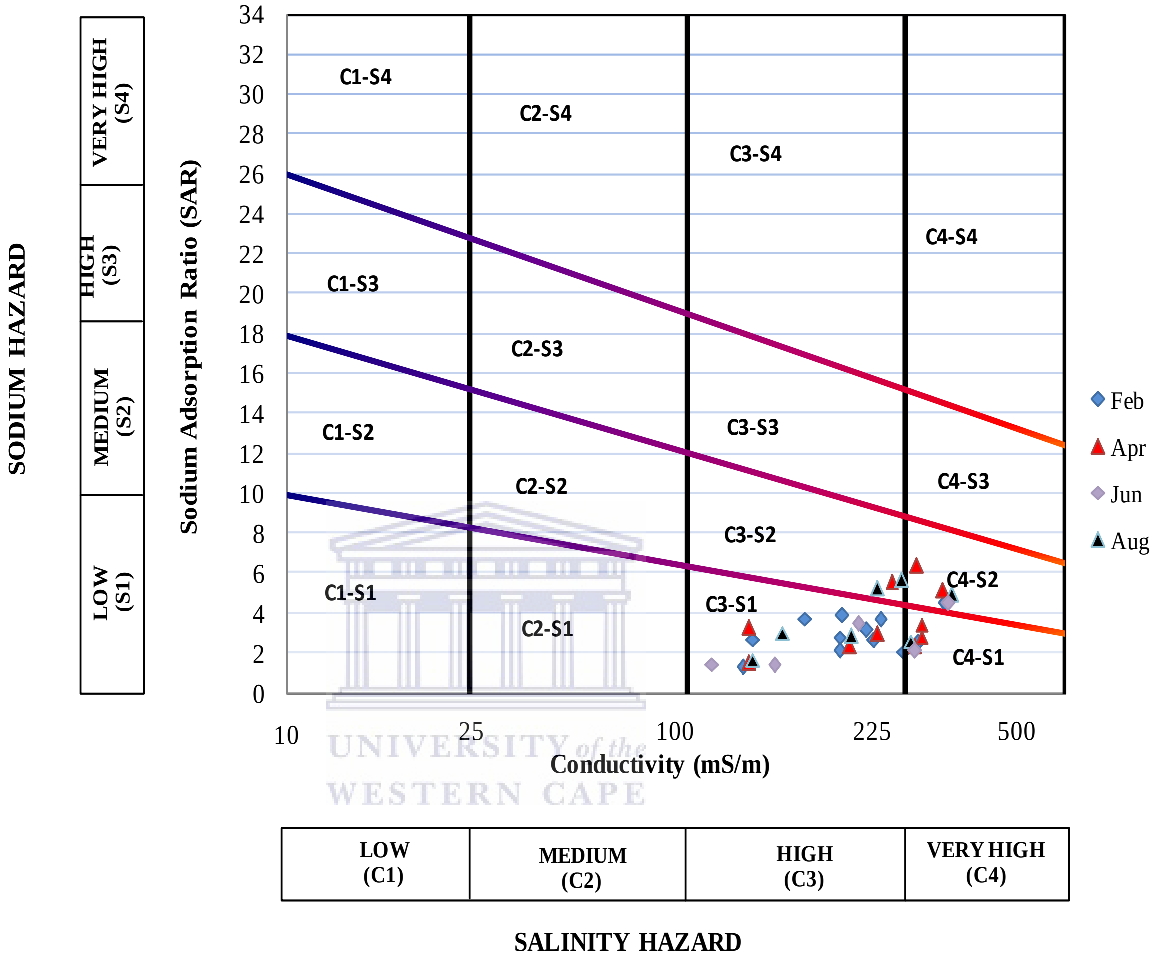


Fig 5.21a: Salinity diagram classification of irrigation water based on Richards, 1954 (BH water during the sampling period)

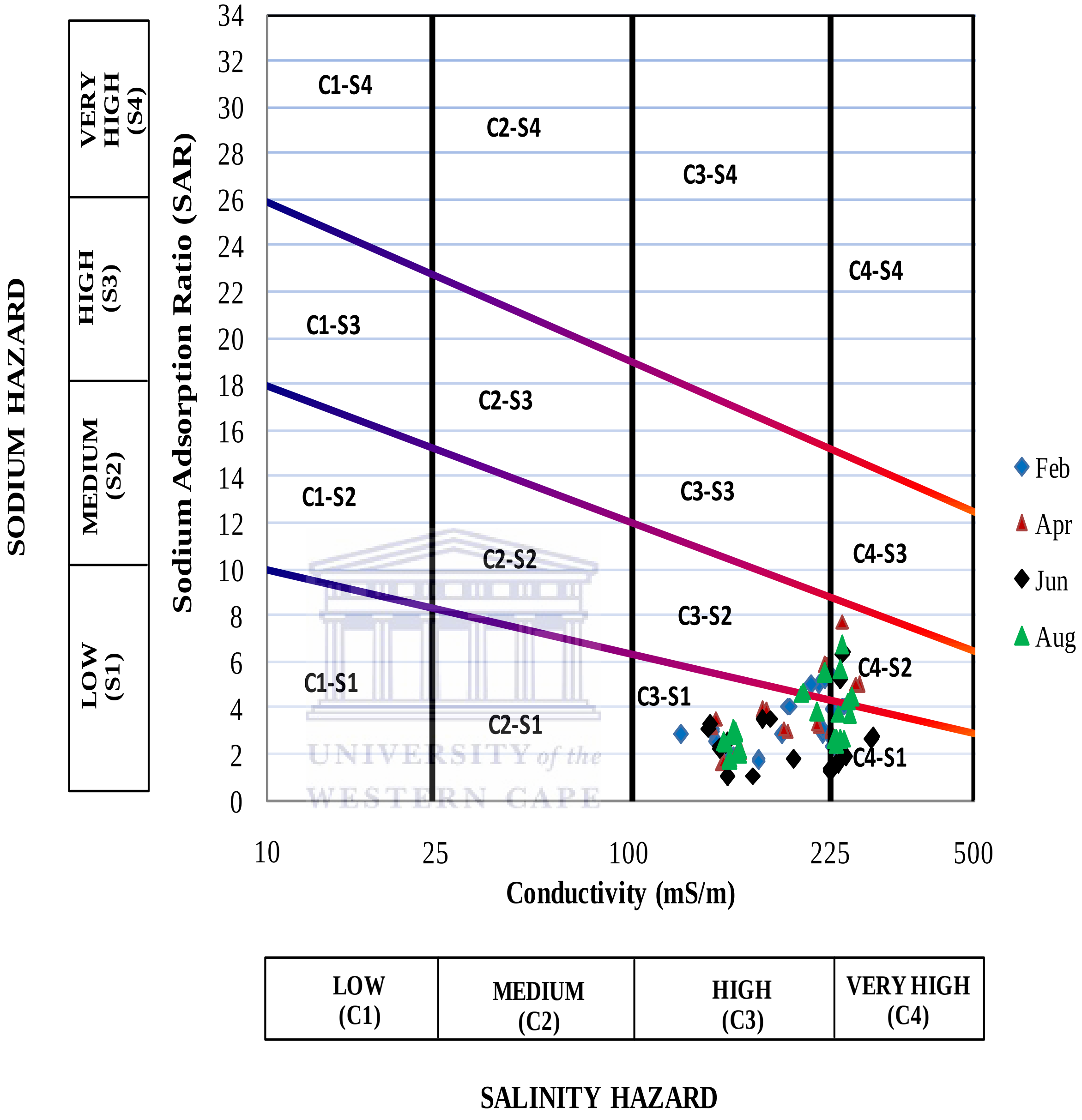


Fig 5.21b: Salinity diagram classification of irrigation water based on Richards, 1954 (Pond water during the sampling period)

5.5 Spatial distributions

Table 5.8 included the summary of the TDS values in summer and winter for borehole and pond water respectively. Figures 5.22a, 5.22b, 5.23a and 5.23b, made using Kriging approach of the software Surfer 8, show the patterns in TDS concentration in the study area for borehole and pond water respectively during the entire sampling period. It is observed that:

- In summer, groundwater was mostly fresh in the western and the central part of the study area. The high TDS values are observed in the south-eastern of the study area. The same pattern is also observed in winter period but groundwater tended to be more brackish in the north-western of the study area.
- In summer, most of the pond waters were brackish nature. The fresh pond water is observed only in the middle part of the study area. The pond water with high salinity level is found right in the north-western, the eastern and the south-eastern part particularly. The same pattern is also observed in winter time but the pond waters were a bit diluted in places.
- In the north-western and the eastern part, the salinity levels of the pond water were higher than those of the borehole water. This might be due to the evaporation process and to the irrigation return flow process as some chemical fertilizers go back to the ponds after being spread over the crop area.
- The summer pattern sketches had saltier areas than the winter pattern sketches. This might be due to the effect of the evaporation process.

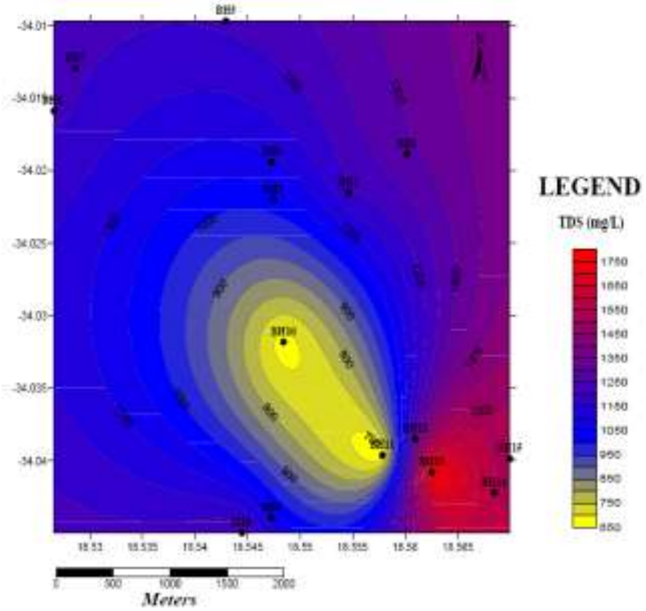


Fig5.22a: TDS spatial distribution of the BH water in summer

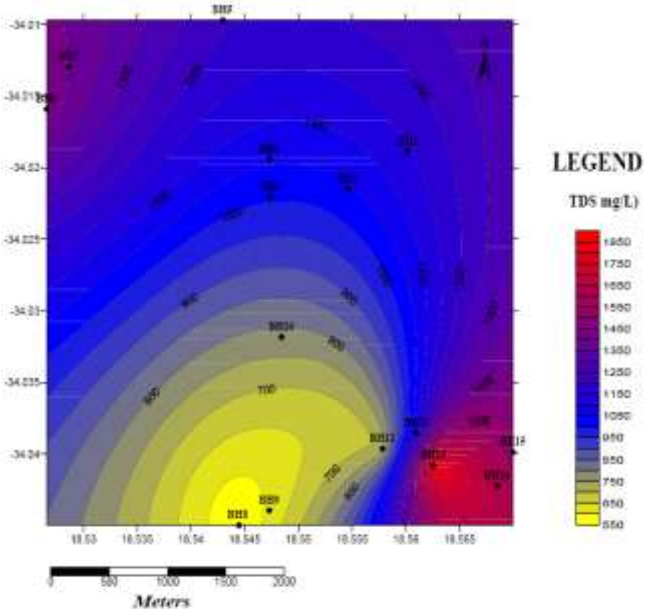


Fig 5.22b: TDS spatial distribution of the BH water in winter

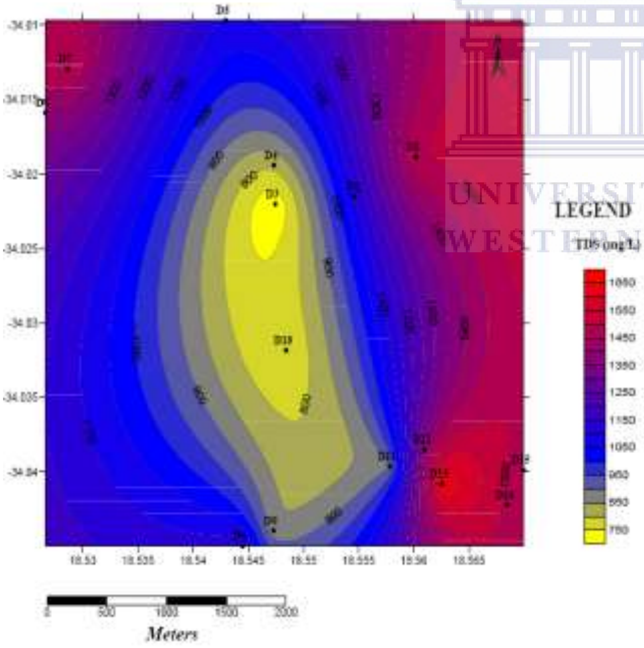


Fig 5.23a: TDS spatial distribution of the pond water in summer

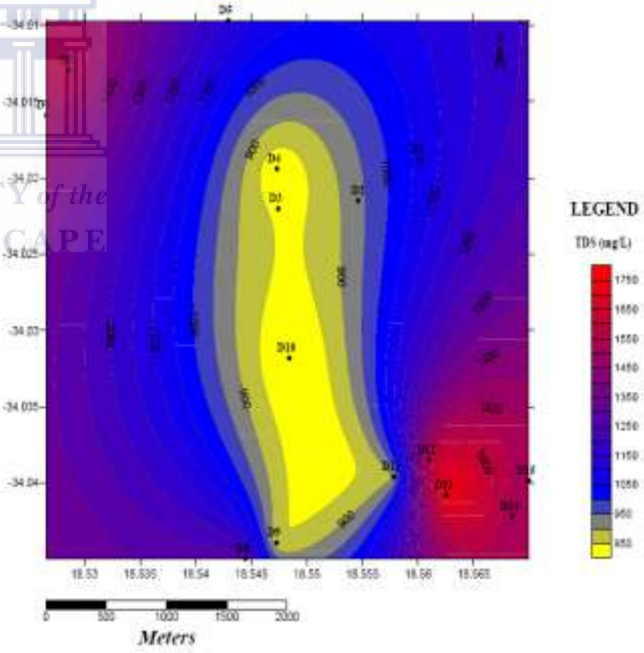


Fig5.23b: TDS spatial distribution of the pond water in winter

5.6 Environmental Isotopes

Results for stable isotopes oxygen-18 and deuterium determined from the collected water samples during the summer in the study area are given in Table 5.9 and are presented in Figure 5.24. Data from recent studies conducted by Adelana et al. (2010) in the Cape Flats region (Table 5.10) were included for comparison purposes. The global and local meteoric waters lines are also plotted on Figure 5.24.

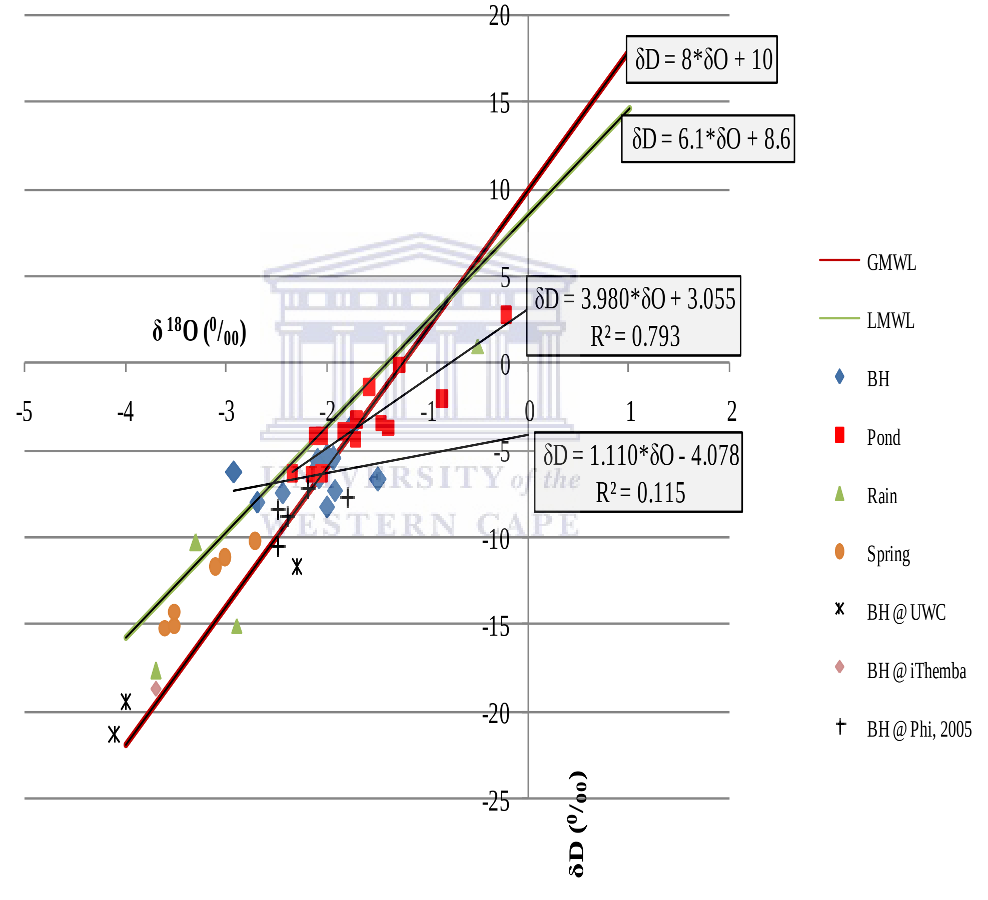


Fig 5.24: Plot of ^{18}O isotope vs ^{2}H isotope data

It is observed that the signature of the stable isotopes of the pond water is laid along a correlative line with a slope of 3.980. This value is in the range of 1-5, which means that the oxygen-18 and deuterium data of the pond followed an evaporation line as stated by Schwartz and Zhang (2003). The pond water is then affected by the evaporation processes in the study area.

However, it is observed that evaporation is not a significant process that affects borehole water in the study area as R^2 value of 0.115 is weak. The water samples of the boreholes collected during the survey in the study area, like the other water samples plotted as well on Figure 5.24, are relatively depleted in the oxygen-18 and deuterium as their plots fell away from and close to the global and the local meteoric water lines.

5.7 Possible origin of the salinity

The origin of water salinity in the study area could be attributed to several probable causes. These include seawater intrusion, accumulation of salt due to agricultural activities, evaporation process and water being pumped from in or near geologic formations with naturally high salinity. The plausible occurrence of these possibilities has been investigated in this section.

5.7.1 Investigation of sea water intrusion

Coastal aquifers that are hydraulically connected to the sea have a saline interface where a zone of contact is formed between the lighter freshwater and the denser underlying sea water within the pore spaces of sediments (Bear, 2007; Craig, 2008). The Ghyben-Herzberg approximation has been developed to represent the freshwater - saltwater interface (Figure 5.25) for homogenous aquifer systems. Under hydrostatic conditions, the weight of a column of freshwater extending from the water table to a point on the interface is the same as a column of salt water extending from sea level to the same depth (Schwartz and Zhang, 2003). This condition can be expressed mathematically as:

$$\rho_s g z = \rho_f g(h_f + z)$$

Or $z = \dfrac{\rho_f}{\rho_s - \rho_f} h_f$

Where ρ_f is the density of freshwater, ρ_s is the density of salt water, z is the height of the salt water column, or the depth below sea level to a point on the interface, h_f is the hydraulic head above sea level, and h_f+z is the height of the freshwater column.

For $\rho_f = 1000\ kg/m^3$ and $\rho_s = 1025\ kg/m^3$,

$z = 40h_f$ (Schwartz and Zhang, 2003)

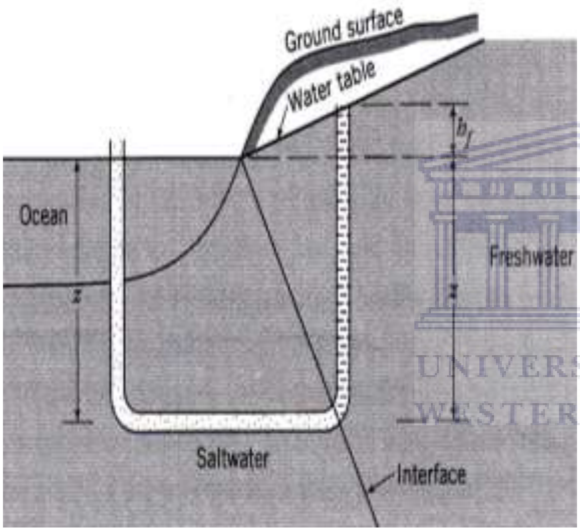


Figure 5.25: Idealization of a coastal saltwater/freshwater system for analysis by the Ghyben-Herzberg relation.
(Schwartz and Zhang, 2003)

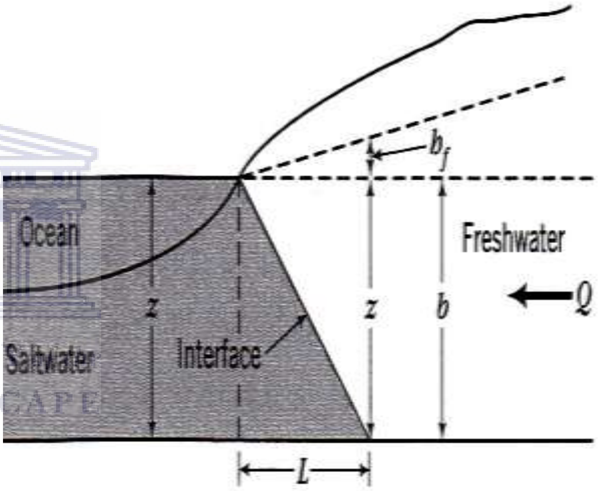


Figure 5.26: Geometry of a coastal aquifer for calculations of the position of the interface and the length of the saltwater wedge for flowing conditions.
(Schwartz and Zhang, 2003)

Recognizing the approximation inherent in the Ghyben-Herzberg relation, more exact solutions for the shape of the interface have been developed from potential flow theory. An improved estimate of the position of the freshwater/saltwater interface is then given as:

$$x = \frac{1}{2} \times \frac{(\rho_s - \rho_f)Kz^2}{\rho_f Q^{'}} \text{ (Schwartz and Zhang, 2003)}$$

Where *K* is the hydraulic conductivity of the aquifer and *Q'* is the discharge rate per unit length of coastline.

For an aquifer with thickness of *b* (Figure 5.26), the length of the saltwater protrusion *(L)* is expressed as:

$$L = \frac{1}{2} \times \frac{(\rho_s - \rho_f)Kb^2}{\rho_f Q^{'}} \text{ (Schwartz and Zhang, 2003)}$$

A conceptual model of groundwater flow system has been developed for the entire Cape Flats aquifer cover up to 350 km^2 (groundwater model report volume 5**,** Cape Flats aquifer model, DWAF 2007). The mass balance results of the survey through different scenarios showed that about 17100 m^3 of water are daily discharged from the Cape Flats Aquifer into the ocean along 18 kilometers approximately of the shoreline. This represents then approximately $9.5\times10^{-1} m^3/day/m$ $(Q' = \frac{17100}{18\times10^3};\qquad Q' = 9.5\times10^{-1} m^3/day/m)$.

This model was tested by considering four different layers with various thickness and hydraulic conductivities as summarizes in the Table 5.11. The average hydraulic conductivity can be estimated as follows:

$$K_{ave} = \frac{17\times10 + 23\times10 + 20\times0.1 + 10\times84}{17 + 23 + 20 + 10}; \qquad K_{ave} = 17.74 m/day$$

Table 5.11: Summary of the characteristics of the different layers of the model

Layer N°	Thickness bn (m)	Hydraulic Conductivity Kn (m/day)	Kn x bn
Layer 1	17	10	170
Layer 2	23	10	230
Layer 3	20	0.1	2
Layer 4	10	84	840

Knowing the average value of the hydraulic conductivity, the value of the discharge rate per unit length of shoreline of the Cape Flats aquifer and the total value of the aquifer thickness; the approximate length of the critical strip from the shoreline within seawater intrusion would occur, could be estimated using the following equation:

$$L = \frac{1}{2} \times \frac{(\rho_s - \rho_f)Kb^2}{\rho_f Q^{'}}$$

$$L = \frac{1}{2} \times \frac{(1025 - 1000) \times 17.74 \times (17 + 23 + 20 + 10)^2}{1000 \times 9.5 \times 10^{-1}}$$

$$L \approx 1150m$$

The boreholes in the study area are located at distance much greater than this critical distance (Table 4.1 in Chapter 4). The hypothesis regarding the seawater intrusion might be then ignored.

5.7.2 Investigation of the effect of agricultural activities

Philippi farming area falls in the Cape Flats region. The various values of total dissolved salts throughout the sampling period in the study area were compared to the TDS values of other places of the region. Table 5.12 and Figure 5.27 show the variations of the TDS in places of the Cape Flats area.

The rainfall water that contributes to the recharge of the Cape Flats aquifer is very fresh water with TDS value less than 47.3 mg/L. The spring water in various places on the Cape Flats area which is the outflow of the circulation of the groundwater is also fresh with TDS values ranging between 86.7 and 125.0 mg/L. At the research site of UWC, groundwaters sampled from the two geological formations of the Cape Flats region are also fresh with TDS values less than 703.0 mg/L. However, the TDS values of groundwater sampled in the Philippi area remain greater than the TDS values of these above waters. The same phenomenon is observed in iThemba site where TDS values are very high. The land use activities are then a major source of the salt load regarding the observed variations of the TDS values across the Cape Flats region. Moreover, the nitrate concentrations in the study area found in groundwater and the pond water exceed the maximal permissible value (5 mg/L) set by DWAF in some places, whereas nitrate elements appear as traces in the groundwater samples from the other places on the Cape Flats region (Table 5.4).

As nitrate pollution in groundwater is one of the common results of intense agriculture (Sililo et al., 2001) and in Philippi farms several fertilizers and pesticides are applied by farmers to maximize their crop's yield (Wright and Conrad, 1995), the agriculture practices could be a source of the increasing of the salinity level in the area.

Table 5.12: TDS value of some particular waters

Sample ID	TDS Values (mg/L)		
	max	min	mean
Rain*	47.3	22.1	35.2
Spring*	125.0	86.7	103.9
UWC Site*	703.0	260.4	417.9
iThemba*	7876.2	6164.7	7004.2
BH Phil 2005*	1223.7	503.0	903.0
BH Phil summer#	1768.0	643.5	1229.8
BH Phil winter#	1846.0	552.5	1195.4
Pond Phil summer#	1709.5	643.5	1175.3
Pond Phil winter#	1846.0	747.5	1237.0

* Data taken from the paper entitled "A conceptual model for the development and management of the Cape Flats Aquifer, South Africa (Adelana et al., 2010)"

\# Current data

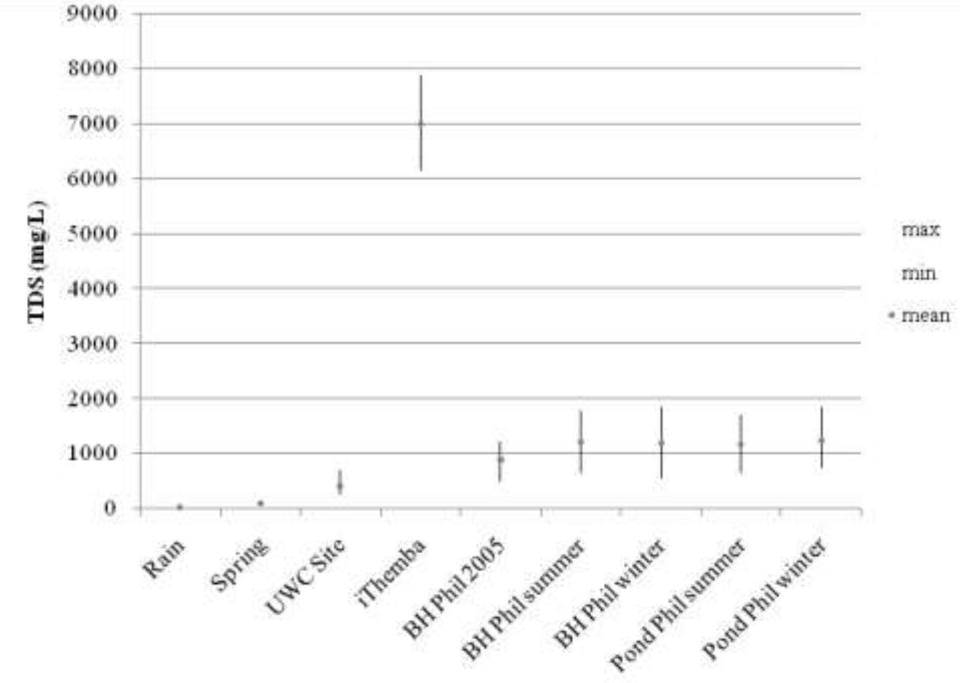


Fig 5.27: Variation of TDS values across the Cape Flats region

5.7.3 Investigation of the effect of evaporation in the study area

Across the study area, the borehole and pond water samples have different signatures of the stable isotopes ^{18}O and deuterium. Table 5.9 summarizes the values of the variation of ^{18}O and deuterium. As depicting in Figures 5.28a and 5.28b, the pond water samples have a relatively enriched isotopic signature than the borehole water samples and some pond water samples have TDS contents greater than the TDS contents of their direct related boreholes which fill up them. Moreover the plot of the δ^{18}O vs δ^{2}H isotope data of the pond water samples in Figure 5.24 lie along the evaporation line as the slope value (3.980) of the correlation line's equation ($\delta D=3.980*\delta O+3.055$) is between 1 and 5. It evidences that the pond water has undergone some degree of evaporation processes in the study area.

Evaporation processes from these open water bodies (pond waters) could therefore be a source of the increasing of the salinity level in the area.

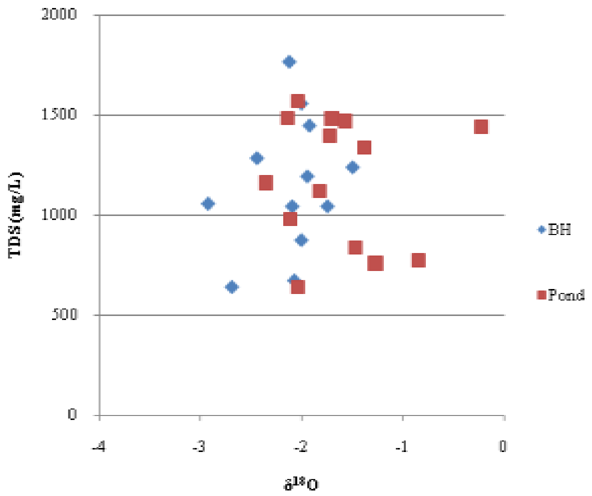


Fig 5.28a: Variation of ^{18}O vs TDS

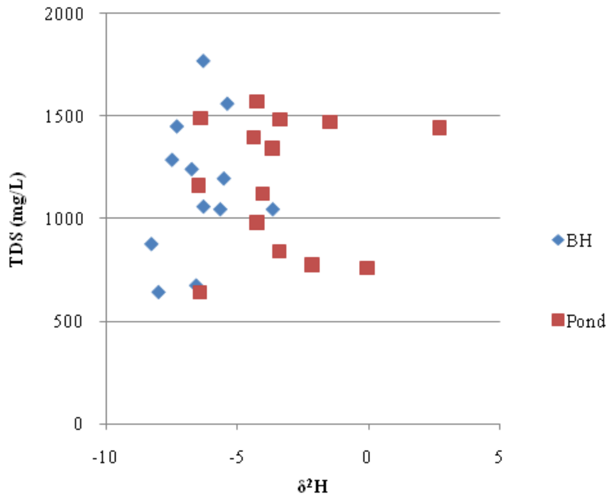


Fig 5.28b: Variation of ^{2}H vs TDS

5.7.4 Investigation of the effect of the geological formation

Through the Piper diagram analysis, groundwater is characterized either by Ca-Cl, Ca-HCO_3, Ca-SO_4 and Na-Cl chemical types in the study area. Some of these hydrochemical facies denote the influence of the dissolution of calcite, halite and gypsum, and the oxidation of pyrite and other sulfide minerals (Younger, 2007). The Cape Flats Aquifer report (DWAF, 2007) indicates that the mostly alkaline character of groundwater observed in 2007, is due to the dissolution of calcrete and carbonate minerals in the aquifer as a result of the effect of rock-water interactions.

The geologic formation within water is pumped to fill up the ponds for irrigating the farms, contributes as well to some extent to the increasing of salt through the process of rock-water interactions.

5.8 Conceptual model of the salinity process in the study area

5.8.1 Circulation of water used for irrigation in the study area

In the study area, water is pumped from the aquifer and stored in the ponds which are like reservoirs. Later the stored water is repumped to irrigate the sub-adjacent crop area. After irrigating the fields, water is taken by plants for growth, some is evaporated, some is returned to ponds, and the remaining infiltrates and percolates further to recharge the aquifer. During rain, the ponds are directly filled up, the crops are directly irrigated and the aquifer is recharged. Further, the water is pumped again from the aquifer to fill up the ponds and the same process continues. Figure 5.29 shows how water circulates for use in the study area.

A conceptual model has been briefly developed to discuss the occurrence of the salinity of the water used for irrigation in the Philippi farming area.

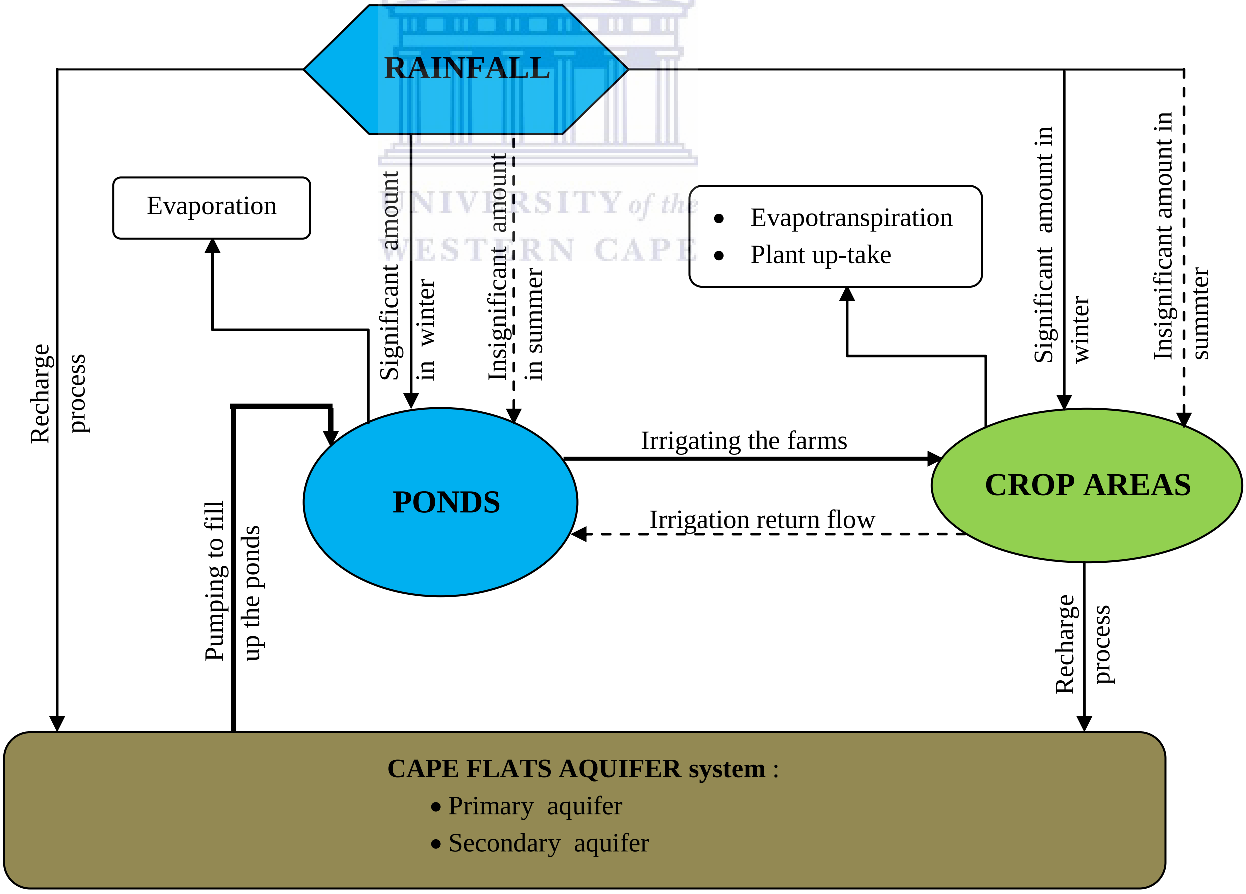


Fig 5.29: Diagram showing the circulation of water used for irrigation in the study area

5.8.2 Possible scenarios from the conceptual model

As it can be seen in Figure 5.29, the pond water is the core of the system. Water from different sources are collected in, stored in and later pumped to irrigate the farms. The sources of the pond water are:

- Groundwater which is greatly pumped in summer.
- Rain which is significant in winter as it is the wet season and little in summer as it is the dry season.
- Return flow water which depends on the amount of the applied irrigation water and the soil ability to whether absorb or not more water.

The conceptual model has been focused on the quality of groundwater found in the Cape Flats region as the main source of the water used for irrigation activities in the study area is the borehole water.

According to Wright and Conrad (1995), groundwater in the main part of the Cape Flats region has generally a fairly low salinity. The changing in groundwater quality in the Cape Flats region that causes the increasing of salts in water could be then explained by considering the following scenarios:

- Scenario 1: Salt is getting loaded due to the natural movement of water through the geologic formation of the Cape Flats region.
- Scenario 2: Salt is getting loaded due to urban contaminations.
- Scenario 3: Salt is getting loaded due the agricultural activities.

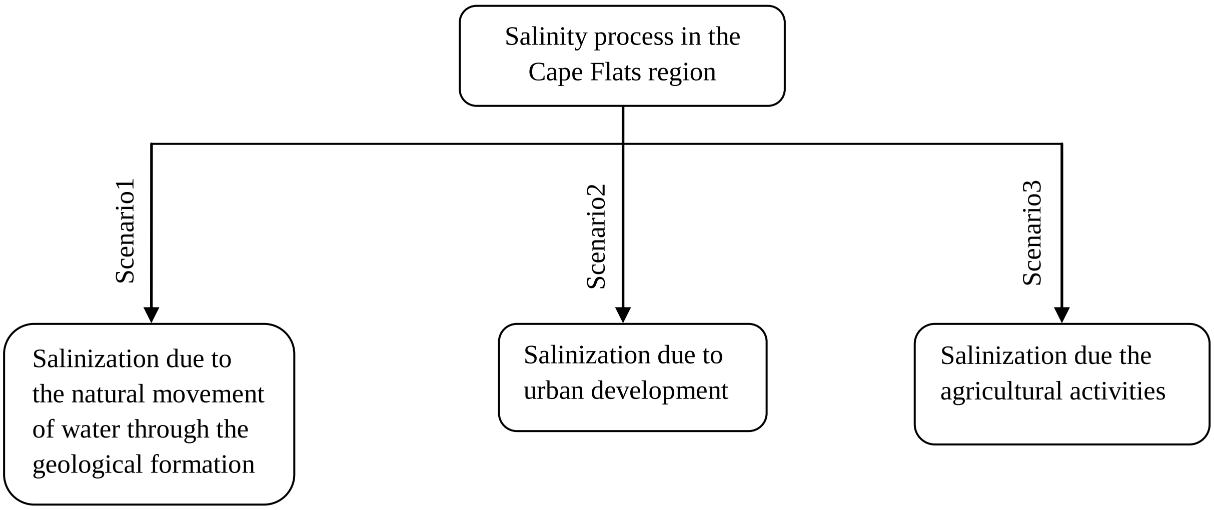


Fig 5.30: Diagram of possible scenarios

Scenario1: *Salt is getting loaded due to the natural movement of water through the geologic formation of the Cape Flats region.*

The geological formation of the Cape Flats region consists of the Cenozoic deposits underlain by essentially impervious Malmesbury or Cape Granite. These deposits include the Sandveld sediment formations that are Witzand, Langebaan, Veldrift, Varswater, and Elandsfontyn formations. They consists mostly of fine to coarse calcareous sands, thin calcareous clay and peat lenses locally (Wright and Conrad, 1995). The calcareous character of the porous medium influences the quality of the groundwater found in places in the Cape Flats region (DWAF, 2007). The Cape Flats Aquifer report (DWAF, 2007) indicates that the mostly alkaline character of groundwater is due to the dissolution of calcrete and carbonate in the aquifer as a result of the effect of rock-water interactions. The geochemical interpretation of the collected samples from the boreholes during the sampling period using the Piper Diagram showed that the groundwater is subjected to ion exchange process and dissolution of, calcite, gypsum and halite amongst others. As water and the geological formations through which water flows constitute a complex dynamic system in which any change of one part of the system is reflected in the other part (Cogho et al., 1989), the natural movement of water through the porous media could be a source that contributes to the load of salt in groundwater found in the Cape Flats region.

Scenario2: *Salt is getting loaded due to urbanization contamination.*

The Cape Town Metropolitan region is experiencing significant urban growth with a continual increase in human population. This urbanization with the various infrastructures and activities that take place puts pressure on the quality on the sandy Cape Flats aquifer. Consequently, both formal and informal settlements in and around the Metropolitan region induce point sources contamination on the Cape Flats aquifer.

Some types of point source contamination due to urban developments include:

- Industrial and municipal solid and liquid waste plants.
- Tank and pipeline Leakage.
- Informal settlement’s sewage systems etc.

Urban development can be a significant source of contamination in growing cities on sandy aquifers. Wright and Conrad (1995) cited, also Wessels and Greeff (1980), that urban planners totally ignored the Cape Flats aquifer when developing the Cape Flats region, and they managed to locate a solid waste disposal site and wastewater treatment works directly above the most productive part of the aquifer. Two waste disposal sites and sewage works were identified by Tredoux (1984) as three major sources of groundwater pollution in the Cape Flats and apart from these three sources; impairment of the water quality could also result from the extensive housing schemes being developed in the areas where the aquifer is best suited for groundwater abstraction (Mehlomakulu, 2000). As Cape Flats region represents a large part of the Cape Town Metropolitan area and its suburbs, residential and commercial developments could be a source that influences the quality of the water that recharges the Cape Flats aquifer and that induces the increasing of salts in this shallow groundwater.

Figure 5.31 illustrates how the quality of the Cape Flats aquifer can be affected due to urban development.

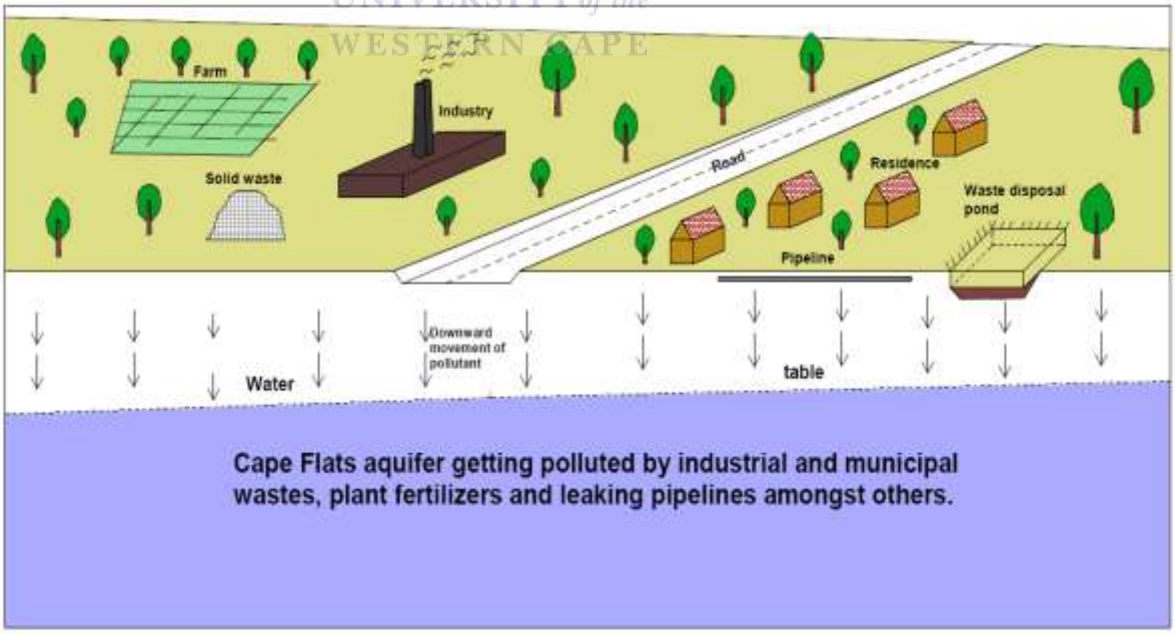


Figure 5.31: Some urban contaminations on the quality of the Cape Flats aquifer.

Scenario3: *Salt is getting loaded due the agricultural activities.*

The agricultural sector is the main water user in the Western Cape (Adelana et al., 2006). The agricultural areas are larger and many tonnes of various fertilizers, manures, insecticides and fungicides are applied over the land of the Cape Flats region every year by farmers to meet their productivity levels. For the Philippi farming area particularly, about 400 odds tonnes of fertilizers are applied over the farms annually (Wright and Conrad, 1995). Agricultural activities identified as posing the most serious threat to groundwater are intensive animal feedlots, use of sewage sludge for preparing land for crop production, use of fertilizers, irrigation and use of pesticides (Tredoux, 1984; Mehlomakulu, 2000). Irrigation is a source of groundwater salinization over large areas as it induces important quantity of soluble salts of the applied water, and the applied fertilizers, insecticides and fungicides to reach the water table when the drainage system of the cultivated area is improperly managed (Kenneth and Neeltje, 2002). In the Philippi area, the accumulation of salts in the soil and in groundwater due to irrigation practices could be examined in three stages:

Short term: Because of the evaporation process in the entire region, salt can get quickly loaded in the pond when water is pumped out from the aquifer and stored in the pond firstly, and when water is applied over the crop area further. The interpretation of the stable isotopes of the pond water supports this idea as the pond water has evidently undergone evaporation processes.

Medium term: The evaporation of the pond water and the applied water over the crop area, and the application of the fertilizers are the constant pressures that can contribute to the accumulation of salts in the study area over time.

Long term: The long term farming activities is a potential source that can increase the load of salt in the study area. Farming has been practiced for more than a century in the Philippi area. The current farmers got the agricultural skills from the parents, and some of them are also training the children currently in order to hand over the farms to them in the future. Even though the farmers have good drainage facilities and good management skills, salt gets accumulated over time at different stage for instance during the evaporation process from the ponds, the evaporation process from the aquifer, the repetition of irrigation over the crop area, and the application of fertilizers, fungicides and insecticides.

The groundwater abstraction practice also is another stress on the salinity level observed in the study area. According to the information given by the farmers over the interviews survey, daily water is pumped from the aquifer for about 12 hours (from 6:00am to 6:00pm) and stored in the ponds. When the pond is not judged enough full for the farmers, they let their pumps run through the night especially during summer. The average rate at which they pumped out groundwater from the aquifer is five liter per second (5 L/s). An estimation of the water quantity that is then withdrawn from a single borehole per day is more than 200 m^3. By considering that there are many boreholes that are running daily, this is a real stress on the available groundwater in the study area and this could easily induce the pumping out of saline water from the deep underlying layers.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

This research investigated the salinity of irrigation waters in the Philippi farming area of the Cape Flats, Cape Town, South Africa. An integrated approach combining a number of specific objectives was adopted in order to achieve the research goal. The findings of the study indicated that the waters are generally suitable for irrigation activities but they have to be used with caution and care as the crops grown in the study area (vegetables) are classified as sensitive and moderately sensitive to salt according to Department of Water Affairs and Forestry, Irrigation Water Guidelines (1996). A detail comparison of the concentrations of some specific ions with the published guidelines of Department of Water Affairs and Forestry, and Food and Agriculture Organization indicated that ions such as chloride, nitrate, potassium and sodium were above the recommended target range in places in the study area. During the field work, not all the selected boreholes were sampled as some of them were switched off and some farmers were not on site to allow the sampling. This may have affected to some extent the spatial distribution of the groundwater salinity but based on the TDS data of the collected samples, the research indicated that the borehole and pond waters were mostly brackish, and fresh waters were only found in the central part of the area. The eastern part had a higher range of salt concentration. The hydrogeochemistry indicated that the waters are characterized either by Ca-Cl, Ca-HCO_3, Ca-SO_4 and Na-Cl chemical types in the study area, and the main processes affecting the ionic composition and concentration of groundwater are ion exchange, and dissolution of calcite, gypsum and halite to some extent. The research indicated that the water samples in the study area displayed different patterns compared with other waters found in the Cape Flats region such as rain, spring water and sea water. Most of the pond water samples showed the same pattern compositions as their related boreholes throughout the year, which revealed that the main source of the pond water was groundwater. The concentration variations of the water constituents did not display much difference throughout the year and this might mean that a monitoring programme could be reduced to once per season instead of twice in this study. Environmental stable isotopes indicated that the pond waters are prone to evaporation processes as their plots lie along an evaporative line, whereas evaporation is not a significant process affecting the ion concentrations of groundwater. The research identified that sea water does not intrude in the study area using the Ghyben-Herzberg approximation of fresh water and saline water interface. The research indicated that the accumulation of salts in the study area was due to the agricultural activities, the evaporation process from the open water bodies (pond waters) and the natural movement of groundwater through the geological formation of the area. Based on the findings of the research, the developed conceptual model on the occurrence of salinity in the area supported these sources of loading salt in the study area.

As the vegetables grown in the study area are sensitive and moderately sensitive to salt, farmers are then encouraged to use the water with caution, and to improve also their drainage systems and management skills so that salt would be leached out from the root zone and would not harm the plant growth. Wright and Conrad (1995) stated that the Cape Flats aquifer represents a geohydrologically important resource that could potentially be exploited as a municipal water supply, and Seward et al. (2009) stated as well that this aquifer could be an alternative source of water supply for the City of Cape Town as the municipality often experiences water supply shortages. Further studies are then ultimately urged to monitor the water quality in the Philippi area continuously as it is an important user of the Cape Flats aquifer at present. Further studies should be undertaken to investigate the impact of all kinds of land use activities including agricultural activities, industrial activities, and informal settlements in and around the whole Cape Flats region on the water quality of the Cape Flats aquifer so as to develop an awareness programme to warn the farmers, owners of industries and residents about the relevant hazards on the Cape Flats aquifer. This would help to maintain the water quality of the Cape Flats aquifer within the recommended standard levels for the various human consumptions and to protect the aquifer for the future developments.

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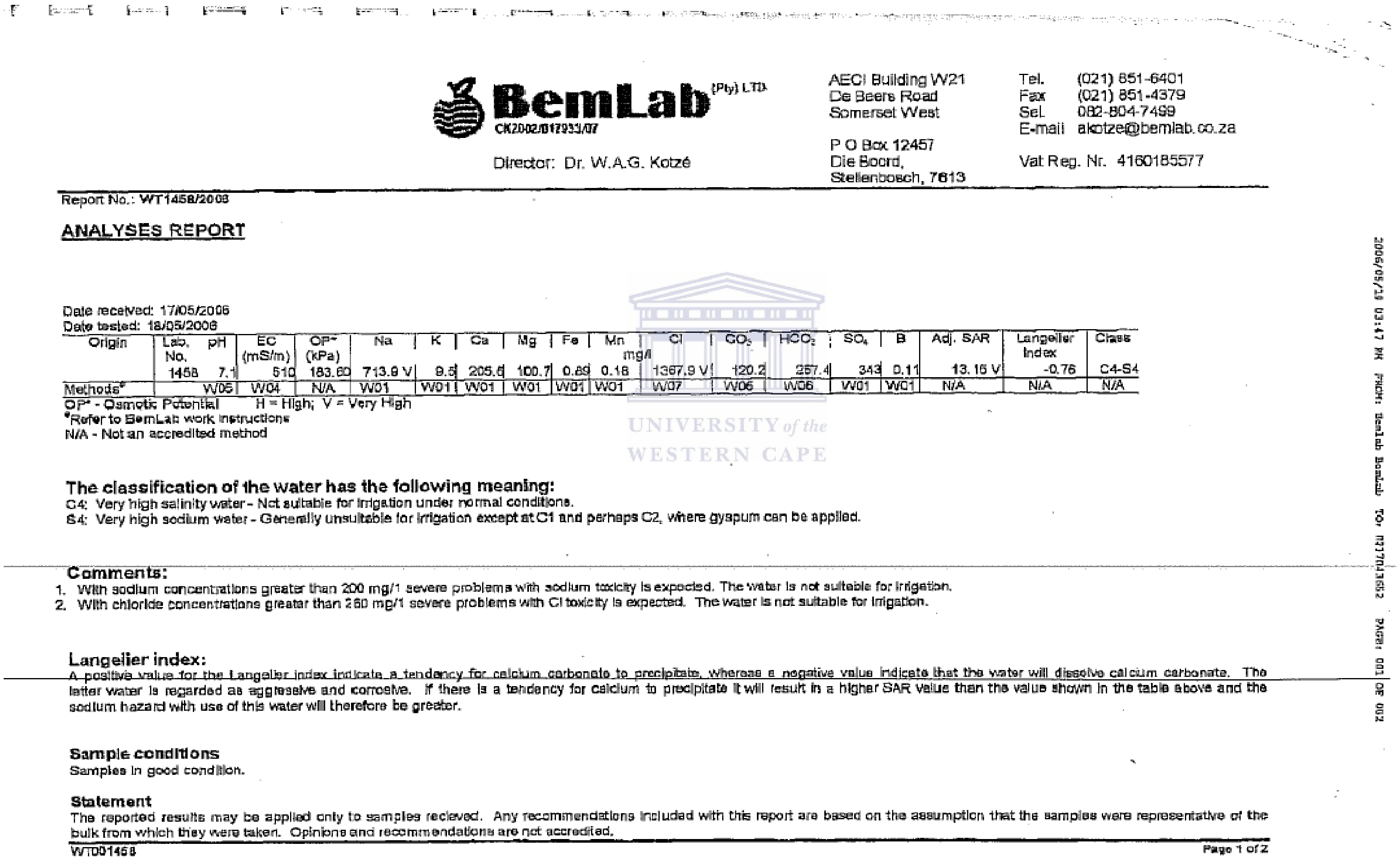
Appendix 1



2006/05/19 03:47 PM FROM: BemLab BemLab TO: 0217043652 PAGE: 001 OF 002

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Vat Reg. Nr. 4160185577

Report No.: WT1458/2006

ANALYSES REPORT

Date received: 17/05/2006
Date tested: 18/05/2006

Origin	Lab. No.	pH	EC (mS/m)	OP* (kPa)	Na	K	Ca	Mg	Fe	Mn	Cl	CO_3	HCO_3	SO_4	B	Adj. SAR	Langelier index	Class
					mg/l													
	1458	7.1	510	183.60	713.9 V	9.5	205.6	100.7	0.89	0.18	1367.9 V	120.2	257.4	343	0.11	13.16 V	-0.76	C4-S4
Methods*		W05	W04	N/A	W01	W01	W01	W01	W01	W01	W07	W06	W06	W01	W01	N/A	N/A	N/A

OP* - Osmotic Potential H = High; V = Very High
*Refer to BemLab work instructions
N/A - Not an accredited method

The classification of the water has the following meaning:
C4: Very high salinity water - Not suitable for irrigation under normal conditions.
S4: Very high sodium water - Generally unsuitable for irrigation except at C1 and perhaps C2, where gypsum can be applied.

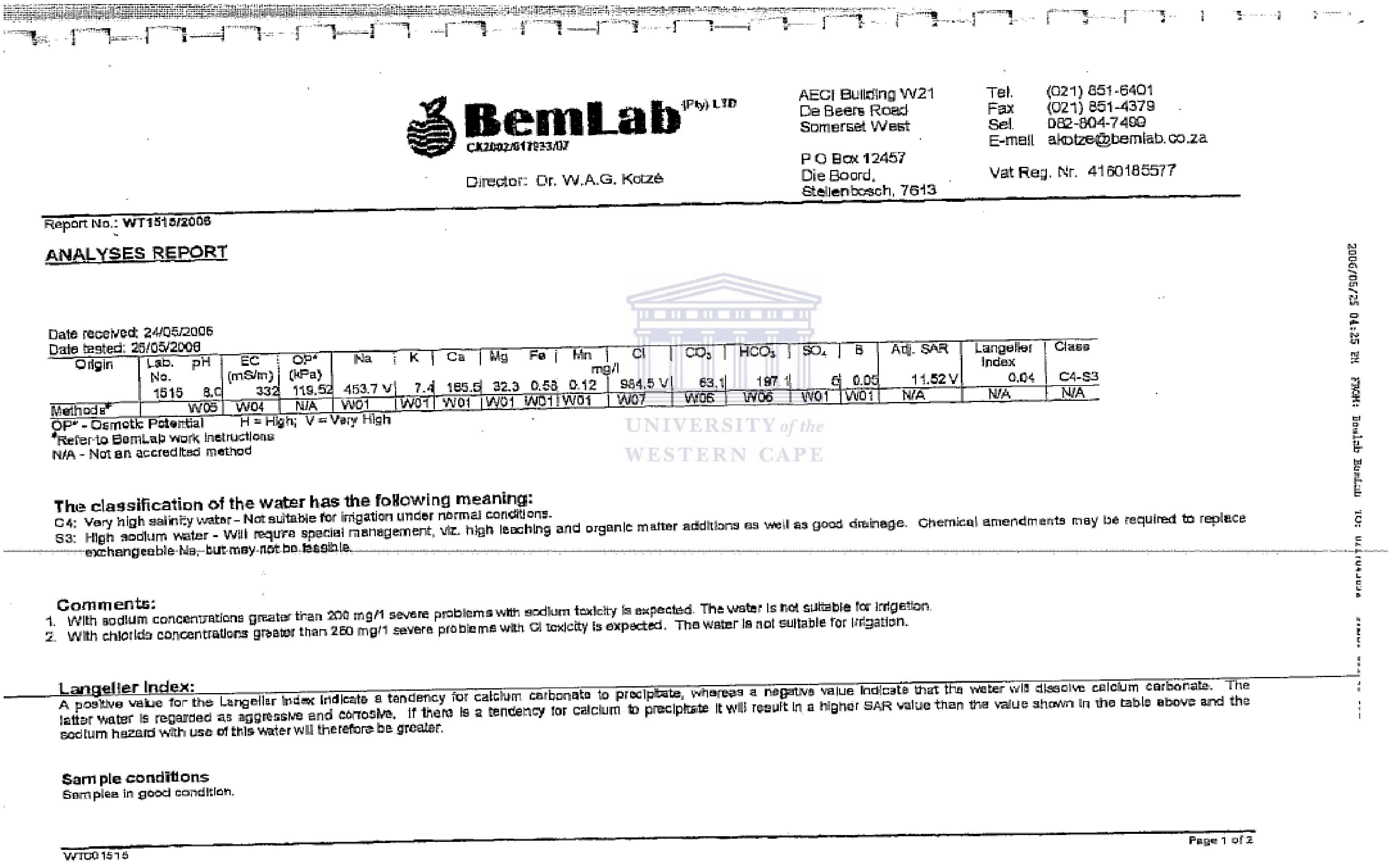
Comments:
1. With sodium concentrations greater than 200 mg/1 severe problems with sodium toxicity is expected. The water is not suitable for irrigation.
2. With chloride concentrations greater than 250 mg/1 severe problems with Cl toxicity is expected. The water is not suitable for irrigation.

Langelier index:
A positive value for the Langelier index indicate a tendency for calcium carbonate to precipitate, whereas a negative value indicate that the water will dissolve calcium carbonate. The latter water is regarded as aggresive and corrosive. If there is a tendency for calcium to precipitate it will result in a higher SAR value than the value shown in the table above and the sodium hazard with use of this water will therefore be greater.

Sample conditions
Samples in good condition.

Statement
The reported results may be applied only to samples recieved. Any recommendations included with this report are based on the assumption that the samples were representative of the bulk from which they were taken. Opinions and recommendations are not accredited.

WT001458 Page 1 of 2



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Report No.: WT1515/2006

ANALYSES REPORT

Date received: 24/05/2006
Date tested: 25/05/2006

Origin	Lab. No.	pH	EC (mS/m)	OP* (kPa)	Na	K	Ca	Mg	Fe	Mn	Cl	CO_3	HCO_3	SO_4	B	Adj. SAR	Langelier Index	Class
					mg/l													
	1515	8.0	332	119.52	453.7 V	7.4	165.5	32.3	0.58	0.12	984.5 V	63.1	197.1	6	0.05	11.52 V	0.04	C4-S3
Methods*		W05	W04	N/A	W01	W01	W01	W01	W01	W01	W07	W06	W06	W01	W01	N/A	N/A	N/A

OP* - Osmotic Potential H = High; V = Very High
*Refer to BemLab work instructions
N/A - Not an accredited method

The classification of the water has the following meaning:

C4: Very high salinity water - Not suitable for irrigation under normal conditions.
S3: High sodium water - Will require special management, viz. high leaching and organic matter additions as well as good drainage. Chemical amendments may be required to replace exchangeable Na, but may not be feasible.

Comments:

1. With sodium concentrations greater than 200 mg/l severe problems with sodium toxicity is expected. The water is not suitable for irrigation.
2. With chloride concentrations greater than 250 mg/l severe problems with Cl toxicity is expected. The water is not suitable for irrigation.

Langelier Index:

A positive value for the Langelier Index indicate a tendency for calcium carbonate to precipitate, whereas a negative value indicate that the water will dissolve calcium carbonate. The latter water is regarded as aggressive and corrosive. If there is a tendency for calcium to precipitate it will result in a higher SAR value than the value shown in the table above and the sodium hazard with use of this water will therefore be greater.

Sample conditions

Samples in good condition.

WTO01515 Page 1 of 2

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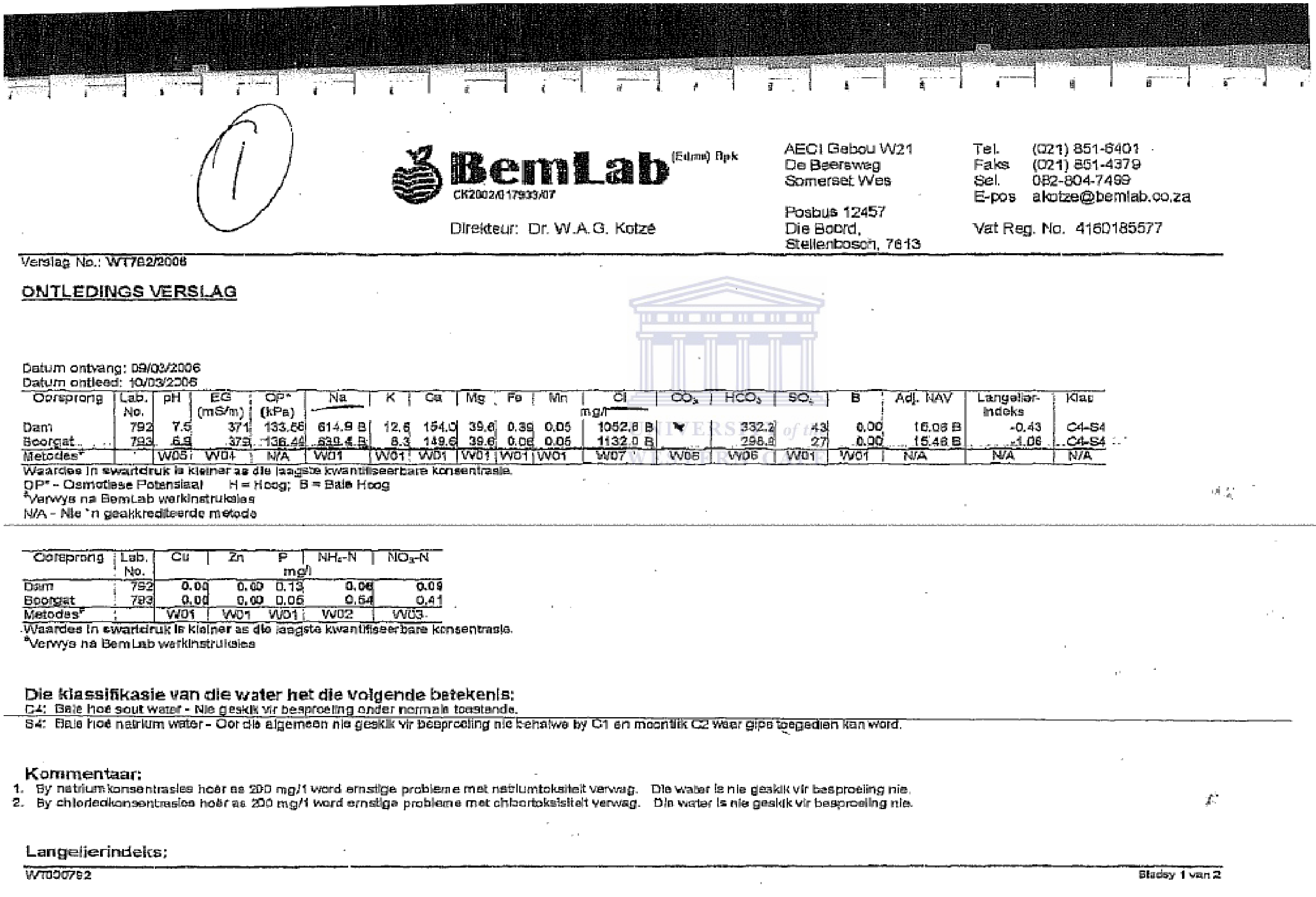

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Verslag No.: WT792/2006

ONTLEDINGS VERSLAG

Datum ontvang: 09/03/2006
Datum ontleed: 10/03/2006

Oorsprong	Lab. No.	pH	EG (mS/m)	OP* (kPa)	Na	K	Ca	Mg	Fe	Mn	Cl	CO_3	HCO_3	SO_4	B	Adj. NAV	Langelier-indeks	Klas
					mg/l													
Dam	792	7.5	371	133.66	614.9 B	12.6	154.0	39.6	0.39	0.05	1052.8 B		332.2	43	0.00	16.06 B	-0.43	C4-S4
Boorgat	793	6.9	379	136.44	639.4 B	8.3	149.6	39.6	0.06	0.05	1132.0 B		298.9	27	0.00	15.46 B	-1.06	C4-S4
Metodes*		W05	W04	N/A	W01	W01	W01	W01	W01	W01	W07	W06	W06	W01	W01	N/A	N/A	N/A

Waardes in swartdruk is kleiner as die laagste kwantifiseerbare konsentrasie.
OP* - Osmotiese Potensiaal H = Hoog; B = Baie Hoog
*Verwys na BemLab werkinstruksies
N/A - Nie 'n geakkrediteerde metode

Oorsprong	Lab. No.	Cu	Zn	P	NH_4-N	NO_3-N
				mg/l		
Dam	792	0.00	0.00	0.13	0.06	0.09
Boorgat	793	0.00	0.00	0.06	0.64	0.41
Metodes*		W01	W01	W01	W02	W03

Waardes in swartdruk is kleiner as die laagste kwantifiseerbare konsentrasie.
*Verwys na BemLab werkinstruksies

Die klassifikasie van die water het die volgende betekenis:

C4: Baie hoë sout water - Nie geskik vir besproeiing onder normale toestande.
S4: Baie hoë natrium water - Oor die algemeen nie geskik vir besproeiing nie behalwe by C1 en moontlik C2 waar gips toegedien kan word.

Kommentaar:

1. By natriumkonsentrasies hoër as 200 mg/l word ernstige probleme met natriumtoksisiteit verwag. Die water is nie geskik vir besproeiing nie.
2. By chloriedkonsentrasies hoër as 200 mg/l word ernstige probleme met chloortoksisiteit verwag. Die water is nie geskik vir besproeiing nie.

Langelierindeks:

WT000792 Bladsy 1 van 2

Appendix 2

RESEARCH QUESTIONNAIRE

I am Ruben, a postgraduate student at University of the Western Cape. My interest is the salinity of the waters used for irrigation purposes in the Philippi farming area. I would appreciate if you could help me by answering the following questions, please.

Farm:
Farmer / Manager:
Address:
Telephone N°:
Email:

- How long has your farm been used for vegetable farming?

…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………

- Which vegetables do you grow:

During summer?	During autumn?

…………………………………………………………………………………………
…………………………………………………………………………………………
……………………………………...………………………………………………

- Which vegetables do you grow:

During winter?	During spring?

…………………………………………………………………………………………
…………………………………………………………………………………………
……………………………………...………………………………………………

- Are there any vegetables that you do not grow anymore? Why?

…………………………………………………………………………………………
…………………………………………………………………………………………
……………………………………...……………………………………………………

- Do you only use dam's water to irrigate your farm?

Yes………. No (specify)……….

- What are the sources of your dam's water?

Rainfall………. Borehole's water………. Irrigation return flow………. Others (specify)……….

- What are the sizes of your dams?

Length…… Width………. Depth……….

- Are your dams underlain by plastic liners?

Yes………. No……….

- How many boreholes do you have? For each one what is the depth of the borehole?

…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………

- How deep is the screened zone of your borehole?

…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………

- In what geologic formation is your borehole screened?

Cape granite………. Malmesbury shale………. Cape Flats sand…………..

- At which rate do you pump your boreholes?
  ……………………………………………………………………………………
  ……………………………………………………………………………………
  ……………………………………………………………………………………

- How long do you pump your boreholes?

Per day………. Per week……… Per month/year………..

- How much water do you pump from your boreholes?
  ……………………………………………………………………………………
  ……………………………………………………………………………………

- Do you apply compost/manure/sludge/fertilizers to your soil?

Yes………. No……….

- If yes, please name them:

……………………………………………………………………………………
……………………………………………………………………………………
…………………………………...………………………………………………

- Do you use fungicides/pesticides on your crops?

Yes……….   No……….

- If yes, please name them:

…………………………………………………………………………………………

…………………………………………………………………………………………

……………………………………...………………………………………………

Thank you / Dankie

Appendix 3

Table 5.1a: Bemlab analyses results of February sampling

Origin	Lab. No.	pH	EC (mS/m)	Osmotic Potential (kPa)	Na^+		K^+	Ca^{2+}	Mg^{2+}	Fe^{2+}	Mn^{2+}	Cl^-		CO_3^-	HCO_3^-	SO_4^{2-}	B	NO_3^-	Adj. SAR		Langelier index	Class
					mg/l																	
BH1	918	7.6	198	71.28	136.8		25.1	232.5	25.3	**0.05**	0.03	321.4	V	33.1	362.1	301	0.04	1	3.67		0.95	C3-S1
BH2	919	7.3	184	66.06	116.4		30.3	214.1	20.7	0.33	0.04	300.2	V	0	336.2	259	0.03	4	3.13		0.51	C3-S1
BH5	920	7	163	58.54	160.2	H	17.3	117.8	22.8	0.35	0.05	401.7	V	0	123.8	118	0.02	0	3.89		-0.42	C3-S1
BH6	921	7.4	135	48.64	114.7		15.8	114.1	19.4	**0.09**	**0.02**	193.4	H	0	389.7	78	0.11	6	3.71		0.47	C3-S1
BH8	922	7.4	191	68.83	104.7		68.4	219.3	28.8	0.69	**0.01**	263.1	V	0	330.1	372	0.07	2	2.63		0.63	C3-S1
BH9	923	7.3	161	58.1	77.5		29.8	238.7	17	9.3	**0.01**	194.2	H	0	323.9	289	0.03	0	2.09		0.52	C3-S1
BH10	924	7.1	104	37.44	83.5		16.1	88.3	14.6	0.26	**0.01**	181	H	0	220	69	0.01	4	2.69		-0.17	C3-S1
BH11	925	7.7	99	35.53	38.8		5.7	157.5	9.8	**0.06**	**0**	98		45.1	282.7	155	0	1	1.31		0.84	C3-S1
BH12	927	7.6	161	57.82	98.2		9.7	213.5	19.6	**0.04**	**0.01**	240.2	V	36.1	336.2	227	0.02	0	2.8		0.89	C3-S1
BH13	926	7.5	272	97.92	173.4	H	33.2	310.8	33.3	**0.07**	**0.01**	480.3	V	30.1	325.5	475	0.06	0	4.5	H	0.9	C4-S2
BH14	928	7.3	240	86.4	114.9		45.5	349	35.3	0.31	**0.01**	292.3	V	0	365.2	661	0.08	0	2.56		0.73	C4-S1
BH15	929	7.3	223	80.28	97.6		45.6	390.9	27.1	1.11	**0.02**	234.9	V	0	270.5	711	0.05	12	2.07		0.62	C3-S1
P1 A	890	7.7	230	82.8	161.5	H	43.3	258.8	31.8	0.2	0.06	376.1	V	90.2	296.4	370	0.09	2	4.11	H	1.14	C4-S2
P1 B	891	8.1	228	82.08	157.6	H	41.5	260.4	32.2	**0.16**	0.05	392	V	78.2	290.3	370	0.09	2	3.95	H	1.51	C4-S2
P3 A	892	8.0	99	35.6	80		15.7	98	13.9	**0.09**	0.06	150.1	H	45.1	290.3	30	0.05	3	2.87		0.99	C3-S1
P3 B	893	7.9	99	35.78	82.1		16.1	100.8	14.4	**0.08**	0.04	145.7		51.1	276.6	28	0.06	3	2.9		0.9	C3-S1
P4 A	894	7.7	120	43.31	82.8		21.9	133.3	16.3	0.59	**0.02**	170.4	H	30.1	223.1	161	0.05	0	2.52		0.67	C3-S1
P4 B	895	8.0	119	42.84	85		22.6	137.3	16.7	0.45	**0.02**	166	H	33.1	226.2	155	0.05	3	2.58		1	C3-S1
P5 A	896	7. 3	178	64.22	180	H	17.5	115.9	23.8	1.09	0.05	451.2	V	0	99.3	112	0.03	2	4.12		-0.32	C3-S1

P5 B	897	7.3	180	64.69	175.8	H	16.4	113.6	23.6	0.77	0.07	468	V	0	103.9	109	0.03	0	4.1		-0.41	C3-S1
P6 A	898	7.5	210	75.6	204.8	V	45.7	130.3	36.4	0.38	0.07	489.2	V	15	209.3	162	0.08	1	5.06	H	0.44	C3-S2
P6 B	899	7.6	203	73.08	200.8	V	44	129.2	35.3	0.47	0.09	465.3	V	18	213.9	151	0.08	1	5.05	H	0.55	C3-S2
P7 A	900	8.0	218	78.48	203.3	V	54.8	137.7	36	**0.1**	0.03	494.5	V	30.1	253.7	145	0.12	32	5.22	H	1.07	C3-S2
P7 B	901	7.7	226	81.36	208.4	V	59.7	144.1	37.8	**0.11**	0.05	499.8	V	21	368.3	142	0.12	30	5.45	H	0.9	C4-S2
P8 A	902	8.0	172	61.74	104.9		42.4	201	23.2	0.25	**0.01**	255.2	V	60.1	270.5	278	0.05	1	2.91		1.26	C3-S1
P8 B	903	7.8	173	62.32	106.6		46	208.1	24.3	**0.17**	**0.01**	251.6	V	48.1	265.9	275	0.05	0	2.86		1.04	C3-S1
P9 A	904	7.7	132	47.48	61.4		30.7	183.6	16.6	0.64	0.05	147.5		30.1	354.5	175	0.04	16	1.88		0.95	C3-S1
P9 B	905	7.8	127	45.65	60.3		28.9	176.1	15.8	0.67	0.04	143		45.1	290.3	170	0.04	13	1.85		1	C3-S1
P10 A	906	8.3	117	42.26	89.4		24.9	111.3	17.7	**0.17**	**0.02**	189.8	H	72.1	249.1	68	0.04	3	2.98		1.36	C3-S1
P10 B	907	8.4	117	41.94	90.6		25.4	114.8	18.4	**0.14**	0.03	194.2	H	108.2	235.3	70	0.04	4	3.06		1.74	C3-S1
P11 A	908	8.0	151	54.22	65.9		39.2	212.1	19.1	0.61	**0.01**	166	H	45.1	241.4	257	0.06	34	1.81		1.2	C3-S1
P11 B	909	8.0	151	54.32	63.5		36.7	213.9	18.8	0.81	**0.01**	167.8	H	51.1	238.4	278	0.05	33	1.76		1.22	C3-S1
P12 A	910	7.8	240	86.4	183.2	H	30.3	265.7	31	**0.09**	**0**	436.2	V	30.1	200.2	443	0.06	27	4.12	H	0.98	C4-S2
P12 B	911	7.7	243	87.48	179.6	H	30.6	273.3	31.2	**0.19**	**0.01**	443.2	V	42.1	210.9	451	0.05	25	4.12	H	0.94	C4-S2
P13 A	912	7.9	215	77.4	118		34.8	278.2	31	**0.19**	**0**	302.9	V	57.1	298	432	0.08	0	2.9		1.3	C3-S1
P13 B	913	7.6	215	77.4	124.7		35.8	285.7	31.5	0.89	**0.01**	304.6	V	45.1	359.1	428	0.08	1	3.09		1.05	C3-S1
P14 A	914	7.7	226	81.36	121.2		49.4	313.7	37.4	0.62	**0.01**	291.4	V	48.1	290.3	624	0.1	3	2.76		1.12	C4-S1
P14 B	915	7.7	227	81.72	121.8		47.9	308.2	36.4	0.35	**0**	292.3	V	60.1	291.9	596	0.1	3	2.84		1.14	C4-S1
P15 A	916	7.7	229	82.44	100.2		42.8	380.6	26.7	0.5	**0.01**	247.2	V	54.1	279.6	781	0.06	9	2.33		1.17	C4-S1
P15 B	917	7.7	228	82.08	102.5		45.5	382.5	26.5	0.55	**0.01**	240.2	V	48.1	275	701	0.06	9	2.36		1.16	C4-S1

Values in **bold** are smaller than the lowest quantifiable concentration.
H = High; V = Very High

Date of sampling: 03/02/10 to 04/02/10
Date of analysis: 26/02/10

Table 5.1b: Bemlab analyses results of April sampling

Origin	Lab. No.	pH	EC (mS/m)	Osmotic Potential (kPa)	Na^+		K^+	Ca^{2+}	Mg^{2+}	Fe^{2+}	Mn^{2+}	Cl^-		CO_3^-	HCO_3^-	SO_4^{2-}	B	NO_3^-	Adj. SAR		Langelier index	Class
					mg/l																	
BH5	2039	6.7	209	75.24	254.3	V	11	112.3	26.7	0.23	0.08	577.2	V	0	84.2	111	0.13	1.0	5.52	H	-0.9	C3-S2
BH6	2040	7.1	238	85.68	279.4	V	27.8	129.5	38	3.1	0.09	643.3	V	0	162.3	132	0.11	5.0	6.35	H	-0.14	C4-S2
BH8	2041	7.6	195	70.34	119.2		74.8	224.8	31.3	0.89	**0.01**	269.6	V	12	330.7	383	0.15	0.0	2.97		0.87	C3-S1
BH9	2042	7.4	169	60.77	88.2		33.3	236.6	18	6.99	**0.01**	201.8	V	0	320	307	0.08	10.0	2.35		0.62	C3-S1
BH10	2043	7.2	102	36.79	99.7		15.1	83.8	14.2	0.77	**0.01**	179.8	H	0	225.1	63	0.06	5.0	3.28		-0.09	C3-S1
BH11	2044	7.8	102	36.76	47.6		8.1	166.2	11.2	**0.1**	**0.01**	96.9		18.1	292.4	170	0.05	1.0	1.51		0.9	C3-S1
BH12	2045	7.5	243	87.48	153.3	H	46.9	314.5	38.9	1	**0.01**	324.3	V	12	332.2	584	0.16	0.0	3.4		0.89	C4-S1
BH13	2046	7.6	271	97.56	226.4	V	37.2	303.1	36.1	**0.18**	**0.01**	471.4	V	15.1	336.8	482	0.12	1.0	5.15	H	0.97	C4-S2
BH14	2047	7.6	236	84.96	108.2		49.5	365.9	27.4	1.08	**0.01**	237.9	V	12	254.2	714	0.11	5.0	2.34		0.91	C4-S1
BH15	2048	7.8	243	87.48	132.2		51.4	352.1	37.7	0.44	**0.01**	304.9	V	18.1	266.4	656	0.15	10.0	2.79		1.15	C4-S1
P3 A	2049	8	120	43.02	109.1		48.7	84.9	21.5	**0.09**	**0.03**	191.2	H	24.1	289.4	84	0.15	0.0	3.55		0.93	C3-S1
P3 B	2050	7.9	120	43.16	111.2		48	86.9	21.8	0.21	**0.03**	192.1	H	21.1	295.5	81	0.15	0.0	3.59		0.84	C3-S1
P4 A	2051	8.2	130	46.94	93.3		32.9	141.8	19	0.42	**0.02**	175.4	H	30.1	343	140	0.11	0.0	2.93		1.35	C3-S1
P4 B	2052	8.2	131	47.12	97.3		33.9	149.3	19.8	0.47	**0.02**	185	H	33.1	343	141	0.11	0.0	3		1.38	C3-S1
P5 A	2053	7.7	155	55.73	152.1	H	22.1	107.2	22.6	0.75	**0.03**	359.5	V	0	145.5	119	0.1	0.0	3.93		-0.08	C3-S1
P5 B	2054	7.8	158	56.77	157.8	H	21.5	107.3	23	0.48	**0.02**	371	V	0	137.8	115	0.07	0.0	4.01		-0.1	C3-S1
P6 A	2055	7.7	220	79.2	245.7	V	37.4	118.7	37.1	0.77	0.07	551.6	V	15.1	170	147	0.1	0.0	5.95	H	0.53	C3-S2
P6 B	2056	7.8	219	78.84	245.6	V	39.2	123	38.4	0.76	0.07	546.3	V	18.1	165.4	149	0.09	0.0	5.87	H	0.65	C3-S2

P7 A	2057	7.9	240	86.4	307.5	V	24.2	115.5	33.6	**0.19**	**0.02**	624.8	V	21.1	174.5	123	0.1	10.0	7.75	H	0.74	C4-S2
P7 B	2058	7.8	241	86.76	309.2	V	24.2	114	33.4	**0.18**	**0.03**	630.9	V	18.1	170	120	0.09	10.0	7.75	H	0.61	C4-S2
P8 A	2059	8.1	177	63.68	113.2		53.2	201.5	25.9	0.25	**0.01**	253.8	V	30.1	316.9	310	0.11	0.0	3.04		1.35	C3-S1
P8 B	2060	8.0	174	62.71	116.7		47.2	198.4	25	0.33	**0.01**	244.1	V	24.1	309.3	280	0.1	0.0	3.14		1.22	C3-S1
P9 A	2061	8.0	137	49.25	70.6		36.2	196.6	17.5	1.04	0.05	149.8		21.1	376.7	188	0.09	25.0	2.12		1.27	C3-S1
P9 B	2062	8.1	135	48.67	70.2		34.4	181.6	16.9	0.83	**0.03**	146.3		27.1	362.9	185	0.09	25.0	2.15		1.35	C3-S1
P10 A	2063	8.1	117	41.94	96.7		24.7	106.3	16.1	0.35	**0.03**	189.5	H	24.1	271	73	0.09	10.0	3.18		1.05	C3-S1
P10 B	2064	8.2	117	41.98	98.1		25.1	108.6	16.2	0.34	0.05	193	H	30.1	278.7	74	0.09	10.0	3.25		1.18	C3-S1
P11 A	2065	8.1	124	44.78	54.7		15.5	187.1	14.1	2.42	**0**	126.9		27.1	287.8	234	0.06	10.0	1.64		1.27	C3-S1
P11 B	2066	8.1	125	45.04	57		15.5	190.7	14.1	3.11	**0**	127.8		30.1	283.3	235	0.07	10.0	1.7		1.27	C3-S1
P12 A	2067	8.1	210	75.6	131.8		31.9	274.6	31.3	0.39	**0**	299.6	V	48.2	318.5	433	0.12	10.0	3.25		1.5	C3-S1
P12 B	2068	8.1	209	75.24	135.3		30.8	271.5	31.5	0.32	**0**	297.8	V	45.2	315.4	424	0.12	10.0	3.33		1.49	C3-S1
P13 A	2069	8	263	94.68	213.2	V	35	293.7	33.9	**0.14**	**0**	459.1	V	60.2	275.6	474	0.12	0.0	5.03	H	1.39	C4-S2
P13 B	2070	8.1	260	93.6	218.1	V	35.5	301.1	34.7	0.4	**0**	454.7	V	54.2	277.1	489	0.12	0.0	5.07	H	1.49	C4-S2
P14 A	2071	8.2	231	83.16	110.6		47.5	365.5	27.9	0.72	**0.01**	239.7	V	45.2	243.4	716	0.11	10.0	2.49		1.6	C4-S1
P14 B	2072	8.2	230	82.8	111.6		48.6	375.4	28.4	0.76	**0.01**	237.9	V	42.2	232.7	728	0.11	10.0	2.46		1.58	C4-S1
P15 A	2073	8.1	224	80.64	131.6		49.9	307	36.9	0.56	**0**	275.8	V	45.2	295.5	566	0.16	10.0	3.02		1.51	C3-S1
P15 B	2074	8.3	225	81	133.6		52	305.3	37.6	0.51	**0.01**	286.4	V	60.2	267.9	596	0.16	10.0	3.06		1.72	C4-S1

Values in **bold** are smaller than the lowest quantifiable concentration.

H = High; V = Very High

Date of sampling: 13/04/10 to 14/04/10

Date of analysis: 28/04/10

Table 5.1c: Bemlab analyses results of June sampling

Origin	Lab. No.	pH	EC (mS/m)	Osmotic Potential (kPa)	Na^+		K^+	Ca^{2+}	Mg^{2+}	Fe^{2+}	Mn^{2+}	Cl^-		CO_3^-	HCO_3^-	SO_4^{2-}	B	NO_3^-	Adj. SAR		Langelier index	Class
					mg/l																	
BH5	3316	6.7	177	63.86	136.9		57.6	108.1	31.9	0.43	**0.01**	364.8	V	0	183.4	201	0.14	1.0	3.45		-0.93	C3-S1
BH8	3317	7.5	85	30.64	39.6		3.8	121.9	8.4	**0.01**	**0**	102.2		0	349.9	71	**0.03**	1.0	1.44		0.52	C3-S1
BH11	3318	7.3	116	41.62	44.2		8.7	182.4	11.2	**0.01**	**0**	113.7		0	336.2	213	0.04	0.0	1.37		0.44	C3-S1
BH13	3319	6.9	278	100.08	197.4	H	29.4	311	35.2	**0.08**	**0.01**	481.1	V	0	368.3	520	0.12	0.0	4.49	H	0.28	C4-S2
BH15	3320	6.9	236	84.96	96		36.3	373.9	26.8	1.15	**0.01**	237.9	V	0	320.9	744	0.11	10.0	2.14		0.28	C4-S1
P 3A	3321	7.6	126	45.25	74.3		28.4	133.9	17.7	**0.09**	**0.02**	162.1	H	0	432.4	91	0.12	25.0	2.43		0.76	C3-S1
P 3B	3322	7.3	127	45.79	77.4		29.9	134	17.7	**0.04**	**0.02**	166.5	H	0	441.6	93	0.12	19.0	2.54		0.47	C3-S1
P 4A	3323	7.6	122	43.81	69.8		23.7	138.4	16.4	**0.11**	**0.01**	156.9	H	0	397.3	128	0.09	1.0	2.26		0.73	C3-S1
P 4B	3324	7.7	122	43.96	75		24.7	137	16.7	0.14	**0.02**	158.6	H	15	353	130	0.09	0.0	2.41		0.82	C3-S1
P 5A	3325	6.9	154	55.44	132.6		29.8	104.6	24.8	**0.1**	**0**	334	V	0	175.7	140	0.09	9.0	3.53		-0.59	C3-S1
P 5B	3326	6.9	162	58.39	137.6		33.5	104.1	26.8	0.16	**0.01**	331.3	V	0	168.1	162	0.18	17.0	3.57		-0.7	C3-S1
P 6A	3327	7.3	238	85.68	211.2	V	51.5	145.2	37.3	**0.08**	**0.02**	499.6	V	0	282.7	169	0.16	58.0	5.23	H	0.34	C4-S2
P 6B	3328	7.3	237	85.32	211.2	V	53.8	144.1	37.8	**0.06**	**0.01**	489.9	V	0	302.6	168	0.16	58.0	5.27	H	0.37	C4-S2
P 7A	3329	7.2	241	86.76	276	V	55.3	147.3	39.4	**0.05**	**0**	571	V	0	212.4	105	**0.03**	53.0	6.39	H	0.12	C4-S2
P 7B	3330	7.2	242	87.12	286.3	V	58.6	147.3	40.3	**0.03**	**0**	571.9	V	0	195.6	104	**0.03**	50.0	6.49	H	0.08	C4-S2
P 8A	3331	8.0	184	66.1	64.4		23.3	162.5	18.6	**0.02**	**0**	296.1	V	45.1	200.2	197	**0**	20.0	1.82		1.46	C3-S1
P 8B	3332	8.5	183	66.02	65.4		24.6	163.1	18.9	**0.01**	**0**	292.6	V	60.1	191	203	**0**	40.0	1.87		1.59	C3-S1
P 9A	3333	7.5	128	45.94	31.6		24.1	125.9	12.8	**0.03**	**0**	140.1		0	369.8	92	**0.01**	40.0	1.07		0.57	C3-S1

P 9B	3334	7.4	127	45.79	31.8		25.2	125.5	13.3	**0.03**	**0.01**	138.3		0	356	94	**0.02**	39.0	1.06		0.46	C3-S1
P 10A	3335	7.9	116	41.87	100.6		26.4	124	17.2	**0.02**	**0**	188.6	H	30.1	334.6	55	**0**	9.0	3.31		0.99	C3-S1
P 10B	3336	8.0	115	41.26	94.3		26.9	114.4	16.8	**0.02**	**0**	180.6	H	36.1	317.8	54	**0**	6.0	3.15		1.06	C3-S1
P 11A	3337	7.6	152	54.61	38.4		21.6	162.4	14.6	**0.06**	**0**	261.7	V		252.1	180	**0**	52.0	1.09		0.59	C3-S1
P 11B	3338	7.6	147	52.96	37.7		19.6	161.2	13.6	**0.03**	**0**	169.2	H	0	275	175	**0**	44.0	1.11		0.62	C3-S1
P 12A	3339	7.6	244	87.84	74.2		24.6	239.3	26.1	**0.04**	**0**	346.3	V	0	379	333	0.05	49.0	1.91		0.91	C4-S1
P 12B	3340	7.5	243	87.48	78.6		25.4	242.7	27	**0.12**	**0**	348.1	V	0	346.9	337	0.05	47.0	1.96		0.78	C4-S1
P 13A	3341	7.3	284	102.24	114.8		21.5	257.6	28.2	**0.07**	**0**	497	V	0	343.8	376	**0.03**	6.0	2.79		0.59	C4-S1
P 13B	3342	7.2	283	101.88	109.8		21.1	255.7	27.4	0.12	**0**	495.2	V	0	314.8	371	**0.03**	5.0	2.63		0.45	C4-S1
P 14A	3343	7.6	234	84.24	69.6		26.5	263.7	27.5	**0.04**	**0**	290.8	V	0	265.9	429	**0.04**	0.0	1.61		0.79	C4-S1
P 14B	3344	7.8	233	83.88	65.9		24.9	257.9	26.5	**0.05**	**0**	287.3	V	18	272	439	**0.04**	0.0	1.59		1.05	C4-S1
P 15A	3345	7.6	226	81.36	51.8		24.8	285.9	19.3	**0.07**	**0**	233.5	V	0	270.5	485	**0.01**	8.0	1.24		0.82	C4-S1
P 15B	3346	7.6	225	81	56.9		23.2	287.8	19.7	**0.08**	**0**	232.6	V	0	258.2	490	**0.01**	7.0	1.34		0.8	C4-S1

Values in **bold** are smaller than the lowest quantifiable concentration.
H = High; V = Very High

Date of sampling: 28/06/10
Date of analysis: 28/07/10

Table 5.1d: Bemlab analyses results of August sampling

Origin	Lab. No.	pH	EC (mS/m)	Osmotic Potential (kPa)	Na^+		K^+	Ca^{2+}	Mg^{2+}	Fe^{2+}	Mn^{2+}	Cl^-		CO_3^-	HCO_3^-	SO_4^{2-}	B	NO_3^-	Adj. SAR		Langelier index	Class
					mg/l																	
BH5	3901	6.6	195	70.13	214.7	V	35.7	121.1	28.7	0.39	**0.02**	482.9	V	0	155.9	134	0.09	0.0	5.22	H	-0.7	C3-S2
BH6	3902	7.5	220	79.2	221.4	V	65	129.3	38.4	**0.11**	**0.02**	459.1	V	0	302.6	159	0.16	10.0	5.61	H	0.54	C3-S2
BH10	3903	6.9	121	43.7	92.5		24.7	99.4	17.9	0.79	**0.01**	193	H	0	313.3	82	0.07	6.0	3		-0.17	C3-S1
BH11	3904	7.4	104	37.26	50.3		6.3	148.3	10.4	**0.11**	**0.01**	99.6		0	307.1	159	0.04	2.0	1.63		0.43	C3-S1
BH12	3905	7.2	171	61.63	105.5		10.8	205.6	22.2	**0.03**	**0.01**	245	V	0	345.3	276	0.07	2.0	2.85		0.41	C3-S1
BH13	3906	7.1	284	102.24	218.4	V	39.5	307.4	35.2	0.52	**0.01**	495.2	V	0	351.5	515	0.13	3.0	4.93	H	0.46	C4-S2
BH15	3907	7.2	231	83.16	110		24.7	349	26.1	2	**0.01**	240.6	V	0	363.7	642	0.11	5.0	2.58		0.61	C4-S1
P 3A	3908	7.9	133	47.88	90.9		33.5	137.2	18.2	**0.04**	**0.02**	166.5	H	45.1	404.9	93	0.12	17.0	3.01		1.13	C3-S1
P 3B	3909	7.8	133	47.74	89.5		38.9	133.9	18	**0.06**	**0**	168.3	H	18	411	93	0.12	17.0	2.93		0.98	C3-S1
P 4A	3910	7.9	126	45.4	76		35.7	136.3	16.6	**0.05**	**0**	155.1	H	21	375.9	126	0.1	10.0	2.49		1.05	C3-S1
P 4B	3911	8.1	125	45	77.6		29.3	135.6	17.3	0.28	**0.02**	150.7	H	33.1	357.6	122	0.20	8.0	2.53		1.26	C3-S1
P 5A	3912	6.9	192	69.26	193.7	H	50	115.9	30	0.34	**0.02**	470.6	V	0	148.2	145	0.1	4.0	4.67	H	-0.42	C3-S2
P 5B	3913	6.8	194	69.7	198.8	H	42.7	113.4	29.3	**0.1**	**0.02**	472.3	V	0	137.5	140	0.1	5.0	4.76	H	-0.57	C3-S2
P 6A	3914	7.4	218	78.48	213.1	V	75.6	125.8	37.6	**0.07**	**0.01**	448.5	V	0	322.4	158	0.16	51.0	5.51	H	0.46	C3-S2
P 6B	3915	7.5	219	78.84	216.6	V	67.4	129.2	37.2	**0.09**	**0.02**	456.5	V	0	313.3	158	0.16	51.0	5.56	H	0.55	C3-S2
P 7A	3916	7.7	238	85.68	235.2	V	57.1	132.6	37.2	**0.05**	**0**	559.5	V	15	198.6	150	0.14	40.0	5.7	H	0.62	C4-S2
P 7B	3917	7.5	239	86.04	268.5	V	53.5	133	37.6	**0.03**	**0**	563.1	V	0	299.5	153	0.14	44.0	6.78	H	0.53	C4-S2
P 8A	3918	8.4	208	74.88	153.8	H	63.2	221	30.9	**0.01**	**0**	332.2	V	48.1	252.1	355	0.11	56.0	3.84		2.05	C3-S1

P 8B	3919	8.6	209	75.24	152.1	H	58.4	217.7	29.8	**0.02**	**0**	334	V	51.1	252.1	349	0.11	56.0	3.85		2.05	C3-S1
P 9A	3920	8.1	136	49	63.6		50.9	154.4	18	**0.02**	**0.01**	139.2		27.1	369.8	135	0.11	48.0	2		1.31	C3-S1
P 9B	3921	8.2	136	48.82	70.7		55.4	155	18.9	**0**	**0**	141		30.1	372.8	138	0.11	47.0	2.21		1.42	C3-S1
P 10A	3922	8.0	131	47.05	92.3		30.1	122.7	16.8	**0.09**	**0.02**	189.5	H	24	372.8	77	0.1	28.0	3.08		1.12	C3-S1
P 10B	3923	8.0	130	46.94	84.7		31.3	124.4	16.4	**0.06**	**0.01**	184.2	H	21	379	78	0.1	28.0	2.83		1.12	C3-S1
P 11A	3924	8.2	129	46.37	58.1		23.7	174.7	15.1	**0.09**	**0**	138.3		33.1	287.3	219	0.06	27.0	1.76		1.36	C3-S1
P 11B	3925	7.8	129	46.4	60.4		20.6	172.4	14.4	**0.01**	**0**	141		18	304.1	209	0.06	26.0	1.84		0.93	C3-S1
P 12A	3926	7.6	250	90	163.3	H	54	272	37.6	**0.06**	**0**	362.2	V	0	366.7	447	0.17	73.0	3.77	H	0.95	C4-S2
P 12B	3927	7.5	235	84.6	155.6	H	43.9	277.9	34.9	2.22	**0.01**	336.6	V	0	452.3	442	0.16	64.0	3.79		0.94	C4-S1
P 13A	3928	7.5	248	89.28	185.6	H	32.2	282.7	30.3	3.01	**0.01**	413.3	V	0	328.5	443	0.11	4.0	4.34	H	0.8	C4-S2
P 13B	3929	7.6	253	91.08	191.9	H	30.5	273.8	32.2	0.3	**0.01**	426.5	V	0	337.7	452	0.11	4.0	4.49	H	0.9	C4-S2
P 14A	3930	7.9	232	83.52	118.6		46.9	347.3	27.6	**0.18**	**0**	242.3	V	30.1	262.8	725	0.11	10.0	2.69		1.26	C4-S1
P 14B	3931	7.8	233	83.88	108.7		45.6	343.4	27.1	0.31	**0**	243.2	V	15	285.7	714	0.11	9.0	2.46		1.15	C4-S1
P 15A	3932	7.9	238	85.68	120.1		52.2	300.8	38	**0.06**	**0**	293.4	V	30.1	281.2	652	0.14	2.0	2.68		1.26	C4-S1
P 15B	3933	7.3	242	87.12	127.5		54.3	340	38.1	0.8	0.04	311.9	V	0	317.8	626	0.18	1.0	2.73		0.66	C4-S1

Values in **bold** are smaller than the lowest quantifiable concentration.

H = High; V = Very High

Date of sampling: 04/02/10 to 05/02/10

Date of analysis: 23/08/10

Table 5.2: Factors used for converting concentrations in mg/L to meq/L

Water constituents	**Factor**
Bicarbonate HCO_3^-	0.01639
Calcium Ca^{2+}	0.0499
Carbonate CO_3^-	0.03333
Chroride Cl^-	0.02821
Iron Fe^{2+}	0.03581
Magnesium Mg^{2+}	0.08229
Manganese Mn^{2+}	0.0364
Nitrate NO_3^-	0.01613
Potassium K^+	0.02558
Sodium Na^+	0.0435
Sulfate SO_4^{2-}	0.02082

Source: Hem, 1985 (Younger, 2007)

Table 5.3a: Calculation of the Cation-Anion Balance (February data)

Origin	Na^+	K^+	Ca^{2+}	Mg^{2+}	Fe^{2+}	Mn^{2+}	Cl^-	CO_3^-	HCO_3^-	SO_4^{2-}	NO_3^-	B	sum of cations	Sum of anions	CAB (%)
	meq/L														
BH1	5.951	0.642	11.602	2.082	0.002	0.001	9.067	1.103	5.935	6.267	0.016	- - -	20.279	22.388	-4.941
BH2	5.063	0.775	10.684	1.703	0.012	0.001	8.469	0.000	5.510	5.392	0.065	- - -	18.239	19.436	-3.178
BH5	6.969	0.443	5.878	1.876	0.013	0.002	11.332	0.000	2.029	2.457	0.000	- - -	15.180	15.818	-2.057
BH6	4.989	0.404	5.694	1.596	0.003	0.001	5.456	0.000	6.387	1.624	0.097	- - -	12.688	13.564	-3.338
BH8	4.554	1.750	10.943	2.370	0.025	0.000	7.422	0.000	5.410	7.745	0.032	- - -	19.642	20.610	-2.404
BH9	3.371	0.762	11.911	1.399	0.333	0.000	5.478	0.000	5.309	6.017	0.000	- - -	17.777	16.804	2.813
BH10	3.632	0.412	4.406	1.201	0.009	0.000	5.106	0.000	3.606	1.437	0.065	- - -	9.661	10.213	-2.775
BH11	1.688	0.146	7.859	0.806	0.002	0.000	2.765	1.503	4.633	3.227	0.016	- - -	10.501	12.144	-7.255
BH12	4.272	0.248	10.654	1.613	0.001	0.000	6.776	1.203	5.510	4.726	0.000	- - -	16.788	18.216	-4.078
BH13	7.543	0.849	15.509	2.740	0.003	0.000	13.549	1.003	5.335	9.890	0.000	- - -	26.644	29.777	-5.552
BH14	4.998	1.164	17.415	2.905	0.011	0.000	8.246	0.000	5.986	13.762	0.000	- - -	26.493	27.993	-2.753
BH15	4.246	1.166	19.506	2.230	0.040	0.001	6.627	0.000	4.433	14.803	0.194	- - -	27.188	26.057	2.126
P 1 A	7.025	1.108	12.914	2.617	0.007	0.002	10.610	3.006	4.858	7.703	0.032	- - -	23.673	26.210	-5.085
P 1 B	6.856	1.062	12.994	2.650	0.006	0.002	11.058	2.606	4.758	7.703	0.032	- - -	23.568	26.158	-5.208
P 3 A	3.480	0.402	4.890	1.144	0.003	0.002	4.234	1.503	4.758	0.625	0.048	- - -	9.921	11.169	-5.915
P 3 B	3.571	0.412	5.030	1.185	0.003	0.001	4.110	1.703	4.533	0.583	0.048	- - -	10.202	10.978	-3.663
P 4 A	3.602	0.560	6.652	1.341	0.021	0.001	4.807	1.003	3.657	3.352	0.000	- - -	12.177	12.819	-2.568

P 4 B	3.698	0.578	6.851	1.374	0.016	0.001	4.683	1.103	3.707	3.227	0.048	- - -	12.518	12.769	-0.993
P 5 A	7.830	0.448	5.783	1.959	0.039	0.002	12.728	0.000	1.628	2.332	0.032	- - -	16.060	16.720	-2.012
P 5 B	7.647	0.420	5.669	1.942	0.028	0.003	13.202	0.000	1.703	2.269	0.000	- - -	15.708	17.175	-4.461
P 6 A	8.909	1.169	6.502	2.995	0.014	0.003	13.800	0.500	3.430	3.373	0.016	- - -	19.591	21.120	-3.754
P 6 B	8.735	1.126	6.447	2.905	0.017	0.003	13.126	0.600	3.506	3.144	0.016	- - -	19.232	20.392	-2.926
P 7 A	8.844	1.402	6.871	2.962	0.004	0.001	13.950	1.003	4.158	3.019	0.516	- - -	20.084	22.646	-5.997
P 7 B	9.065	1.527	7.191	3.111	0.004	0.002	14.099	0.700	6.036	2.956	0.484	- - -	20.899	24.276	-7.474
P 8 A	4.563	1.085	10.030	1.909	0.009	0.000	7.199	2.003	4.433	5.788	0.016	- - -	17.596	19.440	-4.978
P 8 B	4.637	1.177	10.384	2.000	0.006	0.000	7.098	1.603	4.358	5.726	0.000	- - -	18.204	18.784	-1.569
P 9 A	2.671	0.785	9.162	1.366	0.023	0.002	4.161	1.003	5.810	3.644	0.258	- - -	14.009	14.876	-3.003
P 9 B	2.623	0.739	8.787	1.300	0.024	0.001	4.034	1.503	4.758	3.539	0.210	- - -	13.475	14.044	-2.068
P 10 A	3.889	0.637	5.554	1.457	0.006	0.001	5.354	2.403	4.083	1.416	0.048	- - -	11.543	13.304	-7.088
P 10 B	3.941	0.650	5.729	1.514	0.005	0.001	5.478	3.606	3.857	1.457	0.065	- - -	11.840	14.463	-9.975
P 11 A	2.867	1.003	10.584	1.572	0.022	0.000	4.683	1.503	3.957	5.351	0.548	- - -	16.047	16.042	0.017
P 11 B	2.762	0.939	10.674	1.547	0.029	0.000	4.734	1.703	3.907	5.788	0.532	- - -	15.951	16.664	-2.187
P 12 A	5.133	0.890	13.882	2.551	0.007	0.000	8.545	1.903	4.884	8.994	0.436	- - -	22.463	24.762	-4.868
P 12 B	5.424	0.916	14.256	2.592	0.032	0.000	8.593	1.503	5.886	8.911	0.403	- - -	23.221	25.296	-4.276
P 13 A	7.969	0.775	13.258	2.551	0.003	0.000	12.305	1.003	3.281	9.223	0.000	- - -	24.557	25.813	-2.494
P 13 B	7.813	0.783	13.638	2.567	0.007	0.000	12.503	1.403	3.457	9.390	0.016	- - -	24.808	26.768	-3.802
P 14 A	5.272	1.264	15.654	3.078	0.022	0.000	8.220	1.603	4.758	12.992	0.048	- - -	25.290	27.622	-4.407
P 14 B	5.298	1.225	15.379	2.995	0.013	0.000	8.246	2.003	4.784	12.409	0.048	- - -	24.911	27.490	-4.923
P 15 A	4.359	1.095	18.992	2.197	0.018	0.000	6.974	1.803	4.583	16.260	0.145	- - -	26.661	29.765	-5.501
P 15 B	4.459	1.164	19.087	2.181	0.020	0.000	6.776	1.603	4.507	14.595	0.145	- - -	26.910	27.626	-1.313

Table 5.3b: Calculation of the Cation-Anion Balance (April data)

Origin	Na^+	K^+	Ca^{2+}	Mg^{2+}	Fe^{2+}	Mn^{2+}	Cl^-	CO_3^-	HCO_3^-	SO_4^{2-}	NO_3^-	B	sum of cations	Sum of anions	CAB (%)
	meq/l														
BH5	11.062	0.281	5.604	2.197	0.008	0.003	16.283	0.000	1.380	2.311	0.016	- - -	19.155	19.990	-2.132
BH6	12.154	0.711	6.462	3.127	0.111	0.003	18.147	0.000	2.660	2.748	0.097	- - -	22.568	23.653	-2.346
BH8	5.185	1.913	11.218	2.576	0.032	0.000	7.605	0.400	5.420	7.974	0.000	- - -	20.924	21.400	-1.124
BH9	3.837	0.852	11.806	1.481	0.250	0.000	5.693	0.000	5.245	6.392	0.161	- - -	18.227	17.491	2.061
BH10	4.337	0.386	4.182	1.169	0.028	0.000	5.072	0.000	3.689	1.312	0.081	- - -	10.101	10.154	0.260
BH11	2.071	0.207	8.293	0.922	0.004	0.000	2.734	0.603	4.792	3.539	0.016	- - -	11.496	11.685	-0.811
BH12	6.669	1.200	15.694	3.201	0.036	0.000	9.149	0.400	5.445	12.159	0.000	- - -	26.799	27.152	-0.654
BH13	9.848	0.952	15.125	2.971	0.006	0.000	13.298	0.503	5.520	10.035	0.016	- - -	28.902	29.373	-0.808
BH14	4.707	1.266	18.258	2.255	0.039	0.000	6.711	0.400	4.166	14.865	0.081	- - -	26.525	26.322	0.572
BH15	5.751	1.315	17.570	3.102	0.016	0.000	8.601	0.603	4.366	13.658	0.161	- - -	27.754	27.390	0.660
P 3 A	4.746	1.246	4.237	1.769	0.003	0.001	5.394	0.803	4.743	1.749	0.000	- - -	12.002	12.689	-2.784
P 3 B	4.837	1.228	4.336	1.794	0.008	0.001	5.419	0.703	4.843	1.686	0.000	- - -	12.204	12.652	-1.803
P 4 A	4.059	0.842	7.076	1.564	0.015	0.001	4.948	1.003	5.622	2.915	0.000	- - -	13.555	14.488	-3.326
P 4 B	4.233	0.867	7.450	1.629	0.017	0.001	5.219	1.103	5.622	2.936	0.000	- - -	14.197	14.879	-2.348
P 5 A	6.616	0.565	5.349	1.860	0.027	0.001	10.141	0.000	2.385	2.478	0.000	- - -	14.419	15.004	-1.989
P 5 B	6.864	0.550	5.354	1.893	0.017	0.001	10.466	0.000	2.259	2.394	0.000	- - -	14.679	15.119	-1.475
P 6 A	10.688	0.957	5.923	3.053	0.028	0.003	15.561	0.503	2.786	3.061	0.000	- - -	20.651	21.911	-2.960
P 6 B	10.684	1.003	6.138	3.160	0.027	0.003	15.411	0.603	2.711	3.102	0.000	- - -	21.014	21.827	-1.899

P 7 A	13.376	0.619	5.763	2.765	0.007	0.001	17.626	0.703	2.860	2.561	0.161	- - -	22.531	23.911	-2.971
P 7 B	13.450	0.619	5.689	2.748	0.006	0.001	17.798	0.603	2.786	2.498	0.161	- - -	22.514	23.847	-2.875
P 8 A	4.924	1.361	10.055	2.131	0.009	0.000	7.160	1.003	5.194	6.454	0.000	- - -	18.481	19.811	-3.475
P 8 B	5.076	1.207	9.900	2.057	0.012	0.000	6.886	0.803	5.069	5.830	0.000	- - -	18.253	18.588	-0.909
P 9 A	3.071	0.926	9.810	1.440	0.037	0.002	4.226	0.703	6.174	3.914	0.403	- - -	15.287	15.421	-0.437
P 9 B	3.054	0.880	9.062	1.391	0.030	0.001	4.127	0.903	5.948	3.852	0.403	- - -	14.417	15.233	-2.753
P 10 A	4.206	0.632	5.304	1.325	0.013	0.001	5.346	0.803	4.442	1.520	0.161	- - -	11.481	12.272	-3.329
P 10 B	4.267	0.642	5.419	1.333	0.012	0.002	5.445	1.003	4.568	1.541	0.161	- - -	11.676	12.718	-4.272
P 11 A	2.379	0.396	9.336	1.160	0.087	0.000	3.580	0.903	4.717	4.872	0.161	- - -	13.359	14.233	-3.168
P 11 B	2.480	0.396	9.516	1.160	0.111	0.000	3.605	1.003	4.643	4.893	0.161	- - -	13.664	14.306	-2.296
P 12 A	5.733	0.816	13.703	2.576	0.014	0.000	8.452	1.607	5.220	9.015	0.161	- - -	22.841	24.455	-3.411
P 12 B	5.886	0.788	13.548	2.592	0.011	0.000	8.401	1.507	5.169	8.828	0.161	- - -	22.825	24.066	-2.647
P 13 A	9.274	0.895	14.656	2.790	0.005	0.000	12.951	2.006	4.517	9.869	0.000	- - -	27.620	29.343	-3.026
P 13 B	9.487	0.908	15.025	2.855	0.014	0.000	12.827	1.806	4.542	10.181	0.000	- - -	28.290	29.356	-1.849
P 14 A	4.811	1.215	18.238	2.296	0.026	0.000	6.762	1.507	3.989	14.907	0.161	- - -	26.587	27.326	-1.372
P 14 B	4.855	1.243	18.732	2.337	0.027	0.000	6.711	1.407	3.814	15.157	0.161	- - -	27.195	27.250	-0.101
P 15 A	5.725	1.276	15.319	3.037	0.020	0.000	7.780	1.507	4.843	11.784	0.161	- - -	25.377	26.075	-1.358
P 15 B	5.812	1.330	15.234	3.094	0.018	0.000	8.079	2.006	4.391	12.409	0.161	- - -	25.489	27.047	-2.965

Table 5.3c: Calculation of the Cation-Anion Balance (June data)

Origin	Na^+	K^+	Ca^{2+}	Mg^{2+}	Fe^{2+}	Mn^{2+}	Cl^-	CO_3^-	HCO_3^-	SO_4^{2-}	NO_3^-	B	Sum of cations	Sum of anions	CAB (%)
	meq/L														
BH5	5.955	1.473	5.394	2.625	0.015	0.000	10.291	0.000	3.006	4.185	0.016	- - -	15.464	17.498	-6.172
BH8	1.723	0.097	6.083	0.691	0.000	0.000	2.883	0.000	5.735	1.478	0.016	- - -	8.594	10.112	-8.115
BH11	1.923	0.223	9.102	0.922	0.000	0.000	3.207	0.000	5.510	4.435	0.000	- - -	12.169	13.152	-3.884
BH13	8.587	0.752	15.519	2.897	0.003	0.000	13.572	0.000	6.036	10.826	0.000	- - -	27.758	30.435	-4.600
BH15	4.176	0.929	18.658	2.205	0.041	0.000	6.711	0.000	5.260	15.490	0.161	- - -	26.009	27.622	-3.008
P 3A	3.232	0.726	6.682	1.457	0.003	0.001	4.573	0.000	7.087	1.895	0.403	- - -	12.101	13.958	-7.124
P 3B	3.367	0.765	6.687	1.457	0.001	0.001	4.697	0.000	7.238	1.936	0.306	- - -	12.277	14.178	-7.184
P 4A	3.036	0.606	6.906	1.350	0.004	0.000	4.426	0.000	6.512	2.665	0.016	- - -	11.903	13.619	-6.725
P 4B	3.263	0.632	6.836	1.374	0.005	0.001	4.474	0.500	5.786	2.707	0.000	- - -	12.111	13.466	-5.301
P 5A	5.768	0.762	5.220	2.041	0.004	0.000	9.422	0.000	2.880	2.915	0.145	- - -	13.794	15.362	-5.376
P 5B	5.986	0.857	5.195	2.205	0.006	0.000	9.346	0.000	2.755	3.373	0.274	- - -	14.249	15.748	-4.999
P 6A	9.187	1.317	7.245	3.069	0.003	0.001	14.094	0.000	4.633	3.519	0.936	- - -	20.823	23.181	-5.359
P 6B	9.187	1.376	7.191	3.111	0.002	0.000	13.820	0.000	4.960	3.498	0.936	- - -	20.867	23.213	-5.322
P 7A	12.006	1.415	7.350	3.242	0.002	0.000	16.108	0.000	3.481	2.186	0.855	- - -	24.015	22.630	2.969
P 7B	12.454	1.499	7.350	3.316	0.001	0.000	16.133	0.000	3.206	2.165	0.807	- - -	24.621	22.311	4.921
P 8A	2.801	0.596	8.109	1.531	0.001	0.000	8.353	1.503	3.281	4.102	0.323	- - -	13.037	17.562	-14.785
P 8B	2.845	0.629	8.139	1.555	0.000	0.000	8.254	2.003	3.130	4.226	0.645	- - -	13.168	18.260	-16.199
P 9A	1.375	0.616	6.282	1.053	0.001	0.000	3.952	0.000	6.061	1.915	0.645	- - -	9.328	12.574	-14.821

P 9B	1.383	0.645	6.262	1.094	0.001	0.000	3.901	0.000	5.835	1.957	0.629	- - -	9.386	12.322	-13.525
P 10A	4.376	0.675	6.188	1.415	0.001	0.000	5.320	1.003	5.484	1.145	0.145	- - -	12.655	13.098	-1.720
P 10B	4.102	0.688	5.709	1.382	0.001	0.000	5.095	1.203	5.209	1.124	0.097	- - -	11.882	12.728	-3.437
P 11A	1.670	0.553	8.104	1.201	0.002	0.000	7.383	0.000	4.132	3.748	0.839	- - -	11.530	16.101	-16.541
P 11B	1.640	0.501	8.044	1.119	0.001	0.000	4.773	0.000	4.507	3.644	0.710	- - -	11.305	13.634	-9.336
P 12A	3.228	0.629	11.941	2.148	0.001	0.000	9.769	0.000	6.212	6.933	0.790	- - -	17.947	23.704	-13.822
P 12B	3.419	0.650	12.111	2.222	0.004	0.000	9.820	0.000	5.686	7.016	0.758	- - -	18.406	23.280	-11.693
P 13A	4.994	0.550	12.854	2.321	0.003	0.000	14.020	0.000	5.635	7.828	0.097	- - -	20.721	27.580	-14.201
P 13B	4.776	0.540	12.759	2.255	0.004	0.000	13.970	0.000	5.160	7.724	0.081	- - -	20.335	26.934	-13.962
P 14A	3.028	0.678	13.159	2.263	0.001	0.000	8.203	0.000	4.358	8.932	0.000	- - -	19.129	21.493	-5.822
P 14B	2.867	0.637	12.869	2.181	0.002	0.000	8.105	0.600	4.458	9.140	0.000	- - -	18.555	22.303	-9.172
P 15A	2.253	0.634	14.266	1.588	0.003	0.000	6.587	0.000	4.433	10.098	0.129	- - -	18.745	21.247	-6.257
P 15B	2.475	0.593	14.361	1.621	0.002	0.000	6.562	0.000	4.232	10.202	0.113	- - -	19.053	21.108	-5.118

░ Data rows whose CAB is greater than 10%

▓ Discarded data rows as CAB is greater than 15%

Table 5.3d: Calculation of the Cation-Anion Balance (August data)

Origin	Na^+	K^+	Ca^{2+}	Mg^{2+}	Fe^{2+}	Mn^{2+}	Cl^-	CO_3^-	HCO_3^-	SO_4^{2-}	NO_3^-	B	sum of cations	sum of anions	CAB (%)
	meq/L														
BH5	9.339	0.913	6.043	2.362	0.014	0.001	13.623	0.000	2.555	2.790	0.000	- - -	18.672	18.968	-0.785
BH6	9.631	1.663	6.452	3.160	0.004	0.001	12.951	0.000	4.960	3.310	0.694	- - -	20.910	21.915	-1.117
BH10	4.024	0.632	4.960	1.473	0.028	0.000	5.445	0.000	5.135	1.707	0.097	- - -	11.117	12.384	-5.388
BH11	2.188	0.161	7.400	0.856	0.004	0.000	2.810	0.000	5.033	3.310	0.032	- - -	10.609	11.186	-2.644
BH12	4.589	0.276	10.259	1.827	0.001	0.000	6.911	0.000	5.659	5.746	0.032	- - -	16.953	18.349	-3.956
BH13	9.500	1.010	15.339	2.897	0.019	0.000	13.970	0.000	5.761	10.722	0.048	- - -	28.766	30.501	-2.929
BH15	4.785	0.632	17.415	2.148	0.072	0.000	6.787	0.000	5.961	13.366	0.081	- - -	25.052	26.195	-2.232
												- - -			
P 3A	3.954	0.857	6.846	1.498	0.001	0.001	4.697	1.503	6.636	1.936	0.274	- - -	13.157	15.047	-6.700
P 3B	3.893	0.995	6.682	1.481	0.002	0.000	4.748	0.600	6.736	1.936	0.274	- - -	13.053	14.294	-4.538
P 4A	3.306	0.913	6.801	1.366	0.002	0.000	4.375	0.700	6.161	2.623	0.161	- - -	12.388	14.021	-6.182
P 4B	3.376	0.749	6.766	1.424	0.010	0.001	4.251	1.103	5.861	2.540	0.129	- - -	12.326	13.885	-5.947
P 5A	8.426	1.279	5.783	2.469	0.012	0.001	13.276	0.000	2.429	3.019	0.065	- - -	17.970	18.788	-2.226
P 5B	8.648	1.092	5.659	2.411	0.004	0.001	13.324	0.000	2.254	2.915	0.081	- - -	17.814	18.573	-2.085
P 6A	9.270	1.934	6.277	3.094	0.003	0.000	12.652	0.000	5.284	3.290	0.823	- - -	20.578	22.049	-3.450
P 6B	9.422	1.724	6.447	3.061	0.003	0.001	12.878	0.000	5.135	3.290	0.823	- - -	20.658	22.125	-3.428
P 7A	10.231	1.461	6.617	3.061	0.002	0.000	15.783	0.500	3.255	3.123	0.645	- - -	21.372	23.307	-4.331
P 7B	11.680	1.369	6.637	3.094	0.001	0.000	15.885	0.000	4.909	3.185	0.710	- - -	22.780	24.689	-4.021
P 8A	6.690	1.617	11.028	2.543	0.000	0.000	9.371	1.603	4.132	7.391	0.903	- - -	21.878	23.401	-3.363

P 8B	6.616	1.494	10.863	2.452	0.001	0.000	9.422	1.703	4.132	7.266	0.903	- - -	21.426	23.427	-4.460
P 9A	2.767	1.302	7.705	1.481	0.001	0.000	3.927	0.903	6.061	2.811	0.774	- - -	13.255	14.476	-4.401
P 9B	3.075	1.417	7.735	1.555	0.000	0.000	3.978	1.003	6.110	2.873	0.758	- - -	13.782	14.722	-3.298
P 10A	4.015	0.770	6.123	1.382	0.003	0.001	5.346	0.800	6.110	1.603	0.452	- - -	12.294	14.311	-7.580
P 10B	3.684	0.801	6.208	1.350	0.002	0.000	5.196	0.700	6.212	1.624	0.452	- - -	12.045	14.184	-8.155
P 11A	2.527	0.606	8.718	1.243	0.003	0.000	3.901	1.103	4.709	4.560	0.436	- - -	13.097	14.709	-5.796
P 11B	2.627	0.527	8.603	1.185	0.000	0.000	3.978	0.600	4.984	4.351	0.419	- - -	12.942	14.333	-5.096
P 12A	7.104	1.381	13.573	3.094	0.002	0.000	10.218	0.000	6.010	9.307	1.177	- - -	25.154	26.712	-3.004
P 12B	6.769	1.123	13.867	2.872	0.079	0.000	9.495	0.000	7.413	9.202	1.032	- - -	24.711	27.143	-4.692
P 13A	8.074	0.824	14.107	2.493	0.108	0.000	11.659	0.000	5.384	9.223	0.065	- - -	25.606	26.331	-1.397
P 13B	8.348	0.780	13.663	2.650	0.011	0.000	12.032	0.000	5.535	9.411	0.065	- - -	25.451	27.042	-3.030
P 14A	5.159	1.200	17.330	2.271	0.006	0.000	6.835	1.003	4.307	15.095	0.161	- - -	25.967	27.402	-2.689
P 14B	4.728	1.166	17.136	2.230	0.011	0.000	6.861	0.500	4.683	14.865	0.145	- - -	25.272	27.054	-3.406
P 15A	5.224	1.335	15.010	3.127	0.002	0.000	8.277	1.003	4.609	13.575	0.032	- - -	24.699	27.496	-5.359
P 15B	5.546	1.389	16.966	3.135	0.002	0.001	8.799	0.000	5.209	13.033	0.016	- - -	27.041	27.057	-0.030

Table 5.4: Chemical composition of the some water across the Cape Flats region

Sample ID	Description	Location	Latitude S	Longitude E	Depth	pH	EC	TDS	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	Cl^-	SO_4^{2-}	Fe^{2+}	Mn^{2+}	NO_3^-	B
iThr	Rain	iThemba	-33.03	18.71		7.4	4.9	28.5	2.4	0.5	5	0.4	31	15.7	2.3	0.07	0	0.35	0.01
UWCr1	Rain	UWC test site	-33.93	18.62		5.8	20.1	22.1	1	0.4	0.7	0.4	15.1	2.6	1.9	0.05	0.01	1.11	0.01
UWCr2	Rain	UWC test site	-33.93	18.62		6.2	6.8	43	2.7	0.9	9.3	0.5	18.8	17.8	5.6	0.02	0	0.42	0
BEL	Rain	Belhar	-33.95	18.61		4.8	24.8	47.3	1.5	0.3	0	0.1	18	17.9	2.9	0.04	0	6.15	0.01
MS1	Main spring 1	Springs	-33.94	18.42		6.9	18	103.9	3.1	4.6	37	1.4	7.7	44.1	6	0	0.02	0.02	0.01
MS2	Main spring 2	Springs	-33.94	18.41		6.8	17	96.5	3.1	3.2	25.7	1.2	12.2	45	6	0	0.01	0.08	0
MS3	Main spring 3	Springs	-33.94	18.42		6.7	19	115.2	3.6	0.02	28.4	1.2	23	47.7	8	0	0	0	0.01
ALS	Albion spring	Springs	-33.97	18.47		7	20	125	4.7	5.2	26.4	1.5	30.6	45.9	9	0	0.01	1.69	0
KLD	Kildare spring	Maitland	-33.97	18.45		6.8	13	95.8	2.9	2.8	18.2	1.1	30.6	36.2	4	0	0.01	0.03	0
PMS	Palm spring	Springs	-33.97	18.46		6.9	14	86.7	2.3	3.4	19.2	1.3	19.9	35.3	5	0	0.01	0.28	0
UWC4	UWC4	UWC test site	-33.93	18.62	22	7.9	486	301.5	92.8	3.2	6.8	1.4	136.8	33.3	22.5	0.05	0	0.08	0.11
UWC4	UWC4	UWC test site	-33.93	18.62	22	8.2	420.5	260.4	73.9	3.4	10.3	1.1	116.2	27.1	23.4	0.04	0	0.67	0.1
UWC4	UWC4	UWC test site	-33.93	18.62	16.5	7.7	375	346	49.4	4.1	31.9	1.6	192.8	43.7	18	0.13	0	0.04	0.04
UWC5	UWC5	UWC test site	-33.93	18.62	105	5.7	1253	703	70.9	20.7	121.5	27.1	27.1	250.7	170.2	3.28	0.02	7.4	0.15
UWC5	UWC5	UWC test site	-33.93	18.62	94	7.5	791.5	478.7	41.4	9.2	101.2	1.9	152.7	162.6	5.3	0.32	0.07	0.45	0.12
PT1	Pumping well	iThemba	-34.03	18.72		6.9	1191.1	6560	339.1	251.3	1622.5	5.6	342	3854.6	195.1	10.54	0.36	0.28	0.13
PT2	pumping well	iThemba	-34.03	18.72		7.3	1035.4	7876.2	228.2	204.9	1389.4	6.6	211.8	3457.9	167.4	16.44	0.31	1.17	0.15
PT3	Pumping well	iThemba	-34.03	18.72		6.9	1409.7	7415.7	322	288.9	1884.5	17.1	295.9	4319.8	267.4	19.33	0.44	0.05	0.19
PT4	Pumping well	iThemba	-34.03	18.72		7	1201.1	6164.7	269.3	255.6	1660	6.3	267.2	3464.2	225.2	16.16	0.38	0.09	0.17

PH1	Farm	Philippi	-34.01	18.53	40	5.7	1246	698.1	70.7	20.4	117.8	26.9	28.6	251.4	169.5	2.64	0.02	2.11	3.8
PH2	Farm	Philippi	-34.01	18.54	30	6.4	1993	1223.7	141.4	51.6	159.7	61	45.1	337.7	415.5	0.86	0.02	0.96	1.38
PH3	Farm	Philippi	-34.03	18.53	49	6.6	922	503	45.7	14.1	100.4	14.7	61.7	198.7	58.8	0.26	0.02	0.11	0.58
PH4	Farm	Philippi	-34.03	18.53	35	6.6	1505	883.9	98.3	31.7	142.3	37	73.7	276.3	217.9	0.15	0.02	0.25	0.24
PH5	Farm	Philippi	-34.02	18.53	40	7.7	1987	1206.4	167.4	34.2	193.1	36.7	225.5	330	201.1	0.27	0.01	2.36	0.26
Sea water*								35000	410	1350	10500	390	142	19000	2700	0.003	0.002	0.67	4.5
Sea water (1/50)								700	8.2	27	210	7.8	2.84	380	54	0.00006	0.00004	0.0134	0.09

Except the seawater composition data, the remaining data were taken from the paper entitled “A conceptual model for the development and management of the Cape Flats Aquifer, South Africa (Adelana et al., 2010)”.

* Sea water composition data were taken from the paper entitled “Study and interpretation of the chemical characteristics of natural water (Hem, 1985)”.

Table 5.5a: Variation range of the concentrations of the water parameters for the boreholes

		pH	EC (mS/m)	TDS	Na^+	K^+	Ca^{2+}	Mg^{2+}	Fe^{2+}	Mn^{2+}	Cl^-	CO_3^-	HCO_3^-	SO_4^{2-}	B	NO_3^-	Adj. SAR
				mg/l													
Feb	**Max**	7.7	272.00	1768.00	173.40	68.40	390.90	35.30	9.30	0.05	480.30	45.10	389.70	711.00	0.11	10.00	4.50
	Min	7.0	99.00	643.50	38.80	5.70	88.30	9.80	0.04	0.00	98.00	30.10	123.80	69.00	0.00	0.00	1.31
	Mean	7.4	177.58	1154.29	109.73	28.54	220.54	22.81	1.06	0.02	266.73	36.10	305.49	309.58	0.04	2.33	2.92
	Std. dev	0.2	51.94	337.62	36.30	17.90	94.19	7.53	2.62	0.01	103.04	6.48	73.33	212.75	0.03	3.14	0.90
Apr	**Max**	7.8	271.00	1761.50	279.40	74.80	365.90	38.90	6.99	0.09	643.30	18.10	336.80	714.00	0.16	10.00	6.35
	Min	6.7	102.00	663.00	47.60	8.10	83.80	11.20	0.10	0.01	96.90	12.00	84.20	63.00	0.05	0.00	1.51
	Mean	7.4	200.80	1305.20	150.85	35.51	228.88	27.95	1.48	0.03	330.71	14.55	260.43	360.20	0.11	3.80	3.57
	Std. dev	0.3	59.39	386.05	76.96	20.97	102.91	10.35	2.12	0.03	178.07	3.00	83.33	240.28	0.04	3.85	1.58
Jun	**Max**	7.5	278.00	1807.00	197.40	57.60	373.90	35.20	1.15	0.01	481.10	0.00	368.30	744.00	0.14	10.00	4.49
	Min	6.7	85.00	552.50	39.60	3.80	108.10	8.40	0.01	0.00	102.20	0.00	183.40	71.00	0.03	0.00	1.37
	Mean	7.1	178.40	1159.60	102.82	27.16	219.46	22.70	0.34	0.01	259.94	- - -	311.74	349.80	0.09	2.40	2.58
	Std. dev	0.3	80.40	522.61	66.31	21.80	117.82	12.19	0.49	0.01	163.30	- - -	73.84	275.20	0.05	4.28	1.36
Aug	**Max**	7.5	284.00	1846.00	221.40	65.00	349.00	38.40	2.00	0.02	495.20	0.00	363.70	642.00	0.16	10.00	5.61
	Min	6.6	104.00	676.00	50.30	6.30	99.40	10.40	0.03	0.01	99.60	0.00	155.90	82.00	0.04	0.00	1.63
	Mean	7.1	189.43	1231.29	144.69	29.53	194.30	25.56	0.56	0.01	316.49	- - -	305.63	281.00	0.10	4.00	3.69
	Std. dev	0.3	63.19	410.73	71.40	19.72	97.94	9.73	0.69	0.00	159.75	- - -	70.17	214.51	0.04	3.32	1.54

Max : Maximum
Min : Minimum
Std. dev: Standard deviation

Table 5.5b: Variation range of the concentrations of the water parameters for the ponds

		pH	EC (mS/m)	TDS	Na^+	K^+	Ca^{2+}	Mg^{2+}	Fe^{2+}	Mn^{2+}	Cl^-	CO_3^-	HCO_3^-	SO_4^{2-}	B	NO_3^-	Adj. SAR
				mg/l													
Feb	**Max**	8.4	243.00	1579.50	208.40	59.70	382.50	37.80	1.09	0.09	499.80	108.20	368.30	781.00	0.12	34.00	5.45
	Min	7.3	99.00	643.50	60.30	15.70	98.00	13.90	0.08	0.00	143.00	15.00	99.30	28.00	0.03	0.00	1.76
	Mean	7.8	181.18	1177.66	125.57	35.38	202.44	25.85	0.40	0.03	297.91	48.33	257.20	284.36	0.06	9.29	3.27
	Std. dev	0.3	48.72	316.70	49.70	12.24	85.43	8.06	0.28	0.03	128.20	21.56	61.98	206.98	0.03	11.83	1.08
Apr	**Max**	8.3	263.00	1709.50	309.20	53.20	375.40	38.40	3.11	0.07	630.90	60.20	376.70	728.00	0.16	25.00	7.75
	Min	7.7	117.00	760.50	54.70	15.50	84.90	14.10	0.09	0.00	126.90	15.10	137.80	73.00	0.06	0.00	1.64
	Mean	8.0	180.46	1173.00	141.99	35.20	192.83	26.08	0.65	0.02	300.38	33.13	267.18	277.85	0.11	6.54	3.70
	Std. dev	0.2	51.29	333.36	71.34	11.48	90.12	8.07	0.68	0.02	153.88	13.55	68.15	205.99	0.03	7.32	1.63
Jun	**Max**	8.0	284.00	1846.00	286.30	58.60	287.80	40.30	0.16	0.04	571.90	45.10	441.60	490.00	0.18	58.00	6.49
	Min	6.9	115.00	747.50	31.60	19.60	104.10	12.80	0.02	0.00	138.30	15.00	168.10	54.00	0.00	0.00	1.06
	Mean	7.5	190.00	1235.00	105.56	30.28	176.67	23.70	0.07	0.01	303.56	28.86	302.75	217.38	0.06	23.75	2.78
	Std. dev	0.3	58.80	382.21	71.35	11.64	63.50	8.45	0.04	0.01	145.74	12.53	77.08	145.79	0.06	21.07	1.61
Aug	**Max**	8.6	253.00	1644.50	268.50	75.60	347.30	38.10	3.01	0.04	563.10	51.10	452.30	725.00	0.20	73.00	6.78
	Min	6.8	125.00	812.50	58.10	20.60	113.40	14.40	0.00	0.00	138.30	15.00	137.50	77.00	0.06	1.00	1.76
	Mean	7.8	190.62	1239.00	137.19	45.27	195.12	27.12	0.29	0.01	301.53	28.74	315.06	284.58	0.12	28.08	3.52
	Std. dev	0.4	50.51	328.31	60.92	14.00	80.88	8.83	0.70	0.01	140.21	11.37	76.30	211.26	0.03	22.29	1.32

Max : Maximum
Min : Minimum
Std. Dev : Standard deviation

Table 5.5c: Variation range of the concentrations of the water constituents for the boreholes

		Na^+	K^+	Ca^{2+}	Mg^{2+}	Fe^{2+}	Mn^{2+}	Cl^-	CO_3^-	HCO_3^-	SO_4^{2-}	NO_3^-
		meq/L										
Feb	**max**	7 .54	1.75	19.51	2.90	0.33	0.00	13.55	1.50	6.39	14.80	0.19
	min	1.69	0.15	4.41	0.81	0.00	0.00	2.76	0.00	2.03	1.44	0.00
	mean	4.77	0.73	11.01	1.88	0.04	0.00	7.52	0.40	5.01	6.45	0.04
	std dev	1.58	0.46	4.70	0.62	0.09	0.00	2.91	0.60	1.20	4.43	0.06
Apr	**max**	12.15	1.91	18.26	3.20	0.25	0.00	18.15	0.60	5.52	14.87	0.16
	min	2.07	0.21	4.18	0.92	0.00	0.00	2.73	0.00	1.38	1.31	0.00
	mean	6.56	0.91	11.42	2.30	0.05	0.00	9.33	0.29	4.27	7.50	0.06
	std dev	3.35	0.54	5.14	0.85	0.08	0.00	5.02	0.26	1.37	5.00	0.06
Jun	**Max**	8.59	1.47	18.66	2.90	0.04	0.00	13.57	0.00	6.04	15.49	0.16
	Min	1.72	0.10	5.39	0.69	0.00	0.00	2.88	0.00	3.01	1.48	0.00
	mean	4.47	0.69	10.95	1.87	0.01	0.00	7.33	0.00	5.11	7.28	0.04
	Std dev	2.88	0.56	5.88	1.00	0.02	0.00	4.61	0.00	1.21	5.73	0.07
Aug	**max**	9.63	1.66	17.42	3.16	0.07	0.00	13.97	0.00	5.96	13.37	0.16
	min	2.19	0.16	4.96	0.86	0.00	0.00	2.81	0.00	2.56	1.71	0.00
	mean	6.29	0.76	9.70	2.10	0.02	0.00	8.93	0.00	5.01	5.85	0.06
	std dev	3.11	0.50	4.89	0.80	0.02	0.00	4.51	0.00	1.15	4.47	0.05

Max : Maximum
Min : Minimum
Std. dev: Standard deviation

Table 5.5d: Variation range of the concentrations of the water constituents for the ponds

		Na^+	K^+	Ca^{2+}	Mg^{2+}	Fe^{2+}	Mn^{2+}	Cl^-	CO_3^-	HCO_3^-	SO_4^{2-}	NO_3^-
		meq/l										
Feb	**max**	9.07	1.53	19.09	3.11	0.04	0.00	14.10	3.61	6.04	16.26	0.55
	min	2.62	0.40	4.89	1.14	0.00	0.00	4.03	0.00	1.63	0.58	0.00
	mean	5.46	0.90	10.10	2.13	0.01	0.00	8.40	1.50	4.22	5.92	0.15
	std dev	2.16	0.31	4.26	0.66	0.01	0.00	3.62	0.81	1.02	4.31	0.19
Apr	**max**	13.45	1.36	18.73	3.16	0.11	0.00	17.80	2.01	6.17	15.16	0.40
	min	2.38	0.40	4.24	1.16	0.00	0.00	3.58	0.00	2.26	1.52	0.00
	mean	6.18	0.90	9.62	2.15	0.02	0.00	8.47	1.02	4.38	5.78	0.11
	std dev	3.10	0.29	4.50	0.66	0.02	0.00	4.34	0.53	1.12	4.29	0.12
Jun	**Max**	12.45	1.50	14.36	3.32	0.02	0.00	16.13	1.50	7.24	10.20	0.94
	Min	1.37	0.50	5.19	1.05	0.00	0.00	3.90	0.00	2.76	1.12	0.00
	mean	4.59	0.79	8.82	1.95	0.00	0.00	8.56	0.20	4.96	4.53	0.38
	Std dev	3.10	0.31	3.17	0.70	0.00	0.00	4.11	0.44	1.26	3.04	0.34
Aug	**max**	11.68	1.93	17.33	3.14	0.11	0.00	15.89	1.70	7.41	15.09	1.18
	min	2.53	0.53	5.66	1.18	0.00	0.00	3.90	0.00	2.25	1.60	0.02
	mean	5.97	1.16	9.74	2.23	0.01	0.00	8.51	0.59	5.16	5.92	0.45
	std dev	2.65	0.36	4. 04	0.73	0.03	0.00	3.96	0.56	1.25	4.40	0.36

Max : Maximum
Min : Minimum
Std. dev: Standard deviation

Table 5.7: Variation of temperature values for the entire sampling campaigns

	Origin	**Summer**		**Winter**	
		Feb	**Apr**	**Jun**	**Aug**
	P 1	23.5	NS	NS	NS
	P 3	23.9	18.7	15.2	15.0
	P 4	24.4	19.0	14.8	14.6
	P 5	22.9	18.7	14.4	15.9
	P 6	21.6	19.0	14.5	14.0
	P 7	23.5	19.5	14.2	14.4
	P 8	24.4	19.7	15.1	15.0
	P 9	24.7	19.9	15.5	15.4
	P 10	23.5	20.1	14.9	14.7
	P 11	24.4	19.9	16.0	15.7
	P 12	23.4	19.1	15.8	16.0
	P 13	25.1	21.2	16.1	15.9
	P 14	25.6	19.1	15.5	14.9
	P 15	24.7	20.2	15.8	16.0
Min		**18.7**		**14.0**	
Max		**25 .6**		**16.1**	
	BH1	18.3	NS	NS	NS
	BH2	18.3	NS	NS	NS
	BH5	18.2	18.3	15.2	16.9
	BH6	18.8	18.3	NS	14.4
	BH8	19.5	18.9	14.9	NS
	BH9	19.0	19.0	NS	NS
	BH10	18.9	18.8	NS	15.4
	BH11	19.2	19.0	16.5	16.5
	BH12	18.2	18.3	17.3	18.4
	BH13	19.2	18.4	16.4	18.1
	BH14	18.9	18.7	NS	NS
	BH15	19.1	18.5	18.0	18.2
Min		**18.2**		**16.4**	
Max		**19.5**		**18.4**	

NS : No Sample

Table 5.8: Summary of EC and TDS values for the entire sampling campaign

	EC (mS/m)				**TDS (mg/L)**					
ORIGIN	**Feb**	**Apr**	**Jun**	**Aug**	**Feb**	**Apr**	**Jun**	**Aug**	**Summer**	**Winter**
BH1	198.00	NS	NS	NS	1287.00	NS	NS	NS	1287.00	NS
BH2	184.00	NS	NS	NS	1196.00	NS	NS	NS	1196.00	NS
BH5	163.00	209.00	177.00	195.00	1059.50	1358.50	1150.50	1267.50	1209.00	1209.00
BH6	135.00	238.00	NS	220.00	877.50	1547.00	NS	1430.00	1212.25	1430.00
BH8	191.00	195.00	85.00	NS	1241.50	1267.50	552.50	NS	1254.50	552.50
BH9	161.00	169.00	NS	NS	1046.50	1098.50	NS	NS	1072.50	NS
BH10	104.00	102.00	NS	121.00	676.00	663.00	NS	786.50	669.50	786.50
BH11	99.00	102.00	116.00	104.00	643.50	663.00	754.00	676.00	653.25	715.00
BH12	161.00	243.00	NS	171.00	1046.50	1579.50	NS	1111.50	1313.00	1111.50
BH13	272.00	271.00	278.00	284.00	1768.00	1761.50	1807.00	1846.00	1764.75	1826.50
BH14	240.00	236.00	NS	NS	1560.00	1534.00	NS	NS	1547.00	NS
BH15	223.00	243.00	236.00	231.00	1449.50	1579.50	1534.00	1501.50	1514.50	1517.75
P 1	229.00	NS	NS	NS	1488.50	NS	NS	NS	1488.50	NS
P 3	99.00	120.00	126.50	133.00	643.50	780.00	822.25	864.50	711.75	843.38
P 4	119.50	130.50	122.00	125.50	776.75	848.25	793.00	815.75	812.50	804.38
P 5	179.00	156.50	158.00	193.00	1163.50	1017.25	1027.00	1254.50	1090.38	1140.75
P 6	206.50	219.50	237.50	218.50	1342.25	1426.75	1543.75	1420.25	1384.50	1482.00
P 7	222.00	240.50	241.50	238.50	1443.00	1563.25	1569.75	1550.25	1503.13	1560.00
P 8	172.50	175.50	184.00	208.50	1121.25	1140.75	1196.00	1355.25	1131.00	1275.63
P 9	129.50	136.00	127.50	136.00	841.75	884.00	828.75	884.00	862.88	856.38
P 10	117.00	117.00	115.50	130.50	760.50	760.50	750.75	848.25	760.50	799.50
P 11	151.00	124.50	147.00	129.00	981.50	809.25	955.50	838.50	895.38	897.00
P 12	215.00	209.50	243.50	242.50	1397.50	1361.75	1582.75	1576.25	1379.63	1579.50
P 13	241.50	261.50	283.50	250.50	1569.75	1699.75	1842.75	1628.25	1634.75	1735.50
P 14	226.50	230.50	233.50	232.50	1472.25	1498.25	1517.75	1511.25	1485.25	1514.50
P 15	228.50	224.50	225.50	236.67	1485.25	1459.25	1465.75	1538.33	1472.25	1502.04

NS : No Sample

Table 5.9: Results of the stable isotope analysis of the February sampling (Analysis performed at the University of the Witwatersrand Johannesburg)

Origin	δ^2H Report. Value ($^o/_{oo}$)	δ^2H Std. Dev. ($^o/_{oo}$)	δ^{18}O Report. Value ($^o/_{oo}$)	δ^{18}O Std. Dev. ($^o/_{oo}$)
BH1	-7.49	1.14	-2.44	0.26
BH2	-5.51	0.89	-1.94	0.21
BH5	-6.29	2.34	-2.92	0.21
BH6	-8.28	1.49	-2.00	0.25
BH8	-6.74	1.85	-1.49	0.25
BH9	-5.65	1.65	-2.09	0.13
BH10	-6.57	0.79	-2.07	0.08
BH11	-8.01	0.97	-2.69	0.18
BH12	-3.64	1.70	-1.74	0.29
BH13	-6.30	0.93	-2.12	0.16
BH14	-5.38	0.94	-2.00	0.09
BH15	-7.31	1.44	-1.92	0.17
P 1	-6.38	1.17	-2.14	0.10
P 3	-6.40	1.81	-2.04	0.19
P 4	-2.15	1.44	-0.85	0.20
P 5	-6.45	1.41	-2.35	0.30
P 6	-3.66	1.27	-1.38	0.21
P 7	2.68	1.17	-0.23	0.18
P 8	-4.03	1.37	-1.82	0.21
P 9	-3.40	0.77	-1.47	0.29
P 10	-0.05	1.94	-1.27	0.06
P 11	-4.25	1.42	-2.11	0.23
P 12	-4.37	1.72	-1.72	0.25
P 13	-4.25	1.84	-2.04	0.13
P 14	-1.47	1.14	-1.57	0.29
P 15	-3.36	1.33	-1.70	0.24

Date of sampling: 03/02/10 to 04/02/10
Date of analysis: 28/04/10

Table 5.10: Stable isotope composition of some water across the Cape Flats region

Sample ID	Description	Location	^{2}H	^{18}O
iThr	Rain	iThemba	-10.3	-3.3
UWCr1	Rain	UWC test site		
UWCr2	Rain	UWC test site	-17.7	-3.7
BEL	Rain	Belhar	1.0	-0.5
MS1	Main spring 1	Springs	-15.2	-3.6
MS2	Main spring 2	Springs	-14.3	-3.5
MS3	Main spring 3	Springs	-15.1	-3.5
ALS	Albion spring	Springs	-10.3	-2.7
KLD	Kildare spring	Maitland	-11.8	-3.1
PMS	Palm spring	Springs	-11.3	-3.0
UWC4	UWC4	UWC test site	-11.8	-2.3
UWC5	UWC5	UWC test site	-19.6	-4.0
UWC5	UWC5	UWC test site	-21.5	-4.1
PT1	Pumping well	iThemba	-18.7	-3.7
PH1	Farm	Philippi	-7.2	-2.2
PH2	Farm	Philippi	-7.7	-1.8
PH3	Farm	Philippi	-10.5	-2.5
PH4	Farm	Philippi	-8.8	-2.4
PH5	Farm	Philippi	-8.4	-2.5

Data taken from the paper entitled “A conceptual model for the development and management of the Cape Flats Aquifer, South Africa (Adelana et al., 2010)”.