12-2014

GROUNDWATER ASSESSMENT IN SWEIHAN REGION, THE NORTHEAST UNITED ARAB EMIRATES

Maimouna Ali Mohamed Ali Al-Alawi

College of Graduate Studies

جامعة الإمارات العربيـة المتحدة
United Arab Emirates University

United Arab Emirates University

College of Science

Department of Geology

GROUNDWATER ASSESSMENT IN SWEIHAN REGION, THE NORTHEAST UNITED ARAB EMIRATES

Maimouna Ali Mohamed Ali Al-Alawi

This thesis is submitted in partial fulfilment of the requirements for the degree of Master of Science in Environmental Sciences

Under the Supervision of Dr.Ahmed Murad

December 2014

Declaration of Original Work

I, Maimouna Al-Alawi, the undersigned, a graduate student at the United Arab Emirates University (UAEU), am the author of this thesis, entitled "*Groundwater Assessment in Sweihan Region, the Northeast United Arab Emirates*". Hereby, I solemnly declare that this thesis is an original research work that has been done and prepared by me under the supervision of Dr Ahmed Murad, in the College of Science at the UAEU. This work has not been previously formed as the basis for the award of any academic degree, diploma or a similar title at this or any other university. The materials borrowed from other sources and included in my thesis have been properly cited and acknowledged.

Student's Signature ___________________________ Date ______________________

Approval of Master Thesis

This Master Thesis is approved by the following Examining Committee Members:

1) Advisor (Committee Chair): Ahmed Murad

Title: Associate Professor

Department of Geology

College of Science

Signature ______________________________Date______________________

2) Member: Alaa Al-Dahan

Title: Professor

Department of Geology

College of Science

Signature ______________________________Date________________________

3) Member (External Examiner): Dr. Ala Eldin Idris

Water Department

Sharjah Electricity and Water Authority (SEWA)

Signature ______________________________Date________________________

This Master Thesis is accepted by:

1) Dean, College of Science- Professor Frederick Chi-Ching Leung

Signature ________________________ Date________________

2) Dean, College of the Graduate Studies- Professor Nagi T. Wakim

Signature __________________________Date________________

Copy ____ of ____

Abstract

Sweihan is located in the northeast of Abu Dhabi Emirate, the United Arab Emirates. Sweihan landscape is sand dune ridges, which could reach a maximum width of 2 km, and a height of 30 meters, whereas the agricultural fields concentrated in the interdune spaces. Groundwater in Sweihan area is characterized by low recharge amounts, which is being used mainly in irrigation purpose. The intensive agricultural activities in the study area caused depletion and contamination of the groundwater due to heavy uses of organic and chemical fertilizers, as well as heavy pumping. The hydrochemical analysis of 27 samples of groundwater from the study area indicated that the groundwater is characterized by high salinity (high TDS and EC), and high concentrations of chromium, lead, and strontium. Thus, the area of the study is not suitable to be used for domestic uses. Groundwater samples were evaluated for agricultural uses by calculation SAR, TH, Na percentage, MAR. By using these parameters, groundwater of the study area has found to be unsuitable for agricultural purposes. Two water geneses have originated, the first is paleo-marine water origin of Magnesium chloride water type, which indicated over pumping of deep water where old marine deposits was existed. The second is meteoric water origin of sodium sulphate-water type indicating an occurrence of infiltration of rainfall and ion exchange processes. The analysis showed that the dominance of sodium and chloride in the area due to agricultural effluents, gives good reasoning of high salinity in the studied area. Isotopes analysis of hydrogen and oxygen of fifteen groundwater samples emphasized that the study area has high evaporation rates, which affects the groundwater quality.

Keywords: Groundwater assessment, groundwater quality, hydrochemical facies, water genesis origin, aridland agriculture, Sweihan, UAE.

Title and Abstract (in Arabic)

تقيم المياه الجوفية في منطقة سويحان، شمال شرق إمارة أبوظبي

الملخص

تقع منطقة سويحان في شمال شرق إمارة أبو ظبي، الإمارات العربية المتحدة. تتصف المنطقة بطبيعة الكثبان الرملية التي قد يصل ارتفاع بعضها إلى 30 متر وتمتد إلى 2 كيلومتر بينما تتركز المساحات الزراعية بين الكثبان الرملية. تتصف المياه الجوفية في المنطقة بانخفاض معدل التغذية واستخدامها في ري المحاصيل الزراعية. تعاني المياه الجوفية في منطقة الدراسة من النضوب والتلوث نتيجة الإفراط في استخدام الأسمدة العضوية والكيميائية وكذلك الضخ المفرط. نتيجة التحليل الكيميائي لعدد 27 عينة من مياه آبار منطقة الدراسة تبين ارتفاع ملوحة المياه الجوفية (ارتفاع نسبة الأملاح الذائبة والتوصيلية الكهربائية)، وارتفاع تركيز معادن الكروم والرصاص والسترونتيوم ولذلك فإن المياه الجوفية في منطقة الدراسة غير صالحة للاستخدام الآدمي. استخدام معادلات SAR, TH, Na%, MAR لتقييم المياه الجوفية في منطقة الدراسة اثبت بان المياه الجوفية أيضاً غير صالحة للري الزراعي. و من خلال الدراسة الهيدروجيوكيميائية للمياه، تبين وجود مصدرين للمياه الجوفية في منطقة سويحان، المصدر الأول هو المياه العميقة المليئة بالمعادن والأملاح التي تسللت إلى الخزان الجوفي نتيجة الضخ المفرط للمياه الجوفية، والمصدر الثاني هو المياه العذبة التي تدل على وجود عمليات التبادل الأيوني وتسرب مياه الأمطار إلى الخزان الجوفي. وأظهر التحليل أن الصوديوم والكلور هما العنصرين السائدين في المياه الجوفية نسبة إلى النفايات الزراعية السائلة مما يعلل زيادة ملوحة المياه الجوفية في المنطقة المدروسة. أما دراسة النظائر المستقرة لعنصري الهيدروجين والأكسجين في 15 عينة من المياه الجوفية أن نسبة التبخر العالية تأثر في جودة المياه الجوفية في المنطقة.

Acknowledgements

My great thanks first go to ALLAH for giving me the ability and patience to complete my postgraduate study. I am truly grateful and thankful to my supervisor Dr Ahmed Murad, for his thorough guidance to put me at the right track of academic achievements. I am especially grateful to Dr Osman Abdelghany for his great support in geology chapter. I would like to thank Dr Saber Hussein and Mr Omar Al Bashier, for collection of samples and assistance in laboratory work.

Special thanks are due to Hamdi Kandil and Gaber Abdelfatah, for their technical support in mapping. Sincere appreciation to Ahmed Taha for providing the requested references and assisting in reviewing the thesis guidelines. I am truly indebted to the Abu Dhabi Environment Agency and National Drilling Company for their nice welcome and furnishing the required data. Special grateful thanks are given to my family members for charging me with relentless encouragement and support.

Dedication

To my family for continuous encourage and care

To my friends, for moral support and valuable advice

Table of Contents

List of Tables

List of Equations

Plates

List of Figures

List of Abbreviations and Acronyms

°C	Degree Celsius
µS/cm	Micro Siemens per centimetre
ADSSC	Abu Dhabi Sewage Services Company
ADWEA	Abu Dhabi Water and Electricity Authority
EAD	Environment Agency – Abu Dhabi
EC	Electrical Conductivity
FEA	Federal Environment Agency
FEWA	Federal Electricity and Water Authority
GW	Groundwater
Km^2	Square Kilometre
LMWL	Local Meteoric Water Line
meq%	Milliequivalent percent
meq/l	Milliequivalent per litre
mg/l	Milligram per litre
Mgd	Million Gallons per Day
mm	millimetre
Mm^3	Million Cubic Meters
pH	Hydrogen Ion Concentration
SMOW	Standard Mean Ocean Water
UAE	United Arab Emirates

CHAPTER ONE

INTRODUCTION

1.1 Background

The Abu Dhabi Emirate is the largest one of the seven emirates constituting the federal state of the United Arab Emirates (UAE). Abu Dhabi is located at the far west and southwest part of the UAE along the southern coast of Arabian Gulf; Abu Dhabi lays N 24° 28' 0.2202", E 54° 21' 59.976". Its area occupies 87% of the UAE (i.e., about 67,340 km^2). It is bounded by Sultanate of Oman at the east, Saudi Arabia from the south and west; Arabian Gulf at the north as shown in (Figure 1).

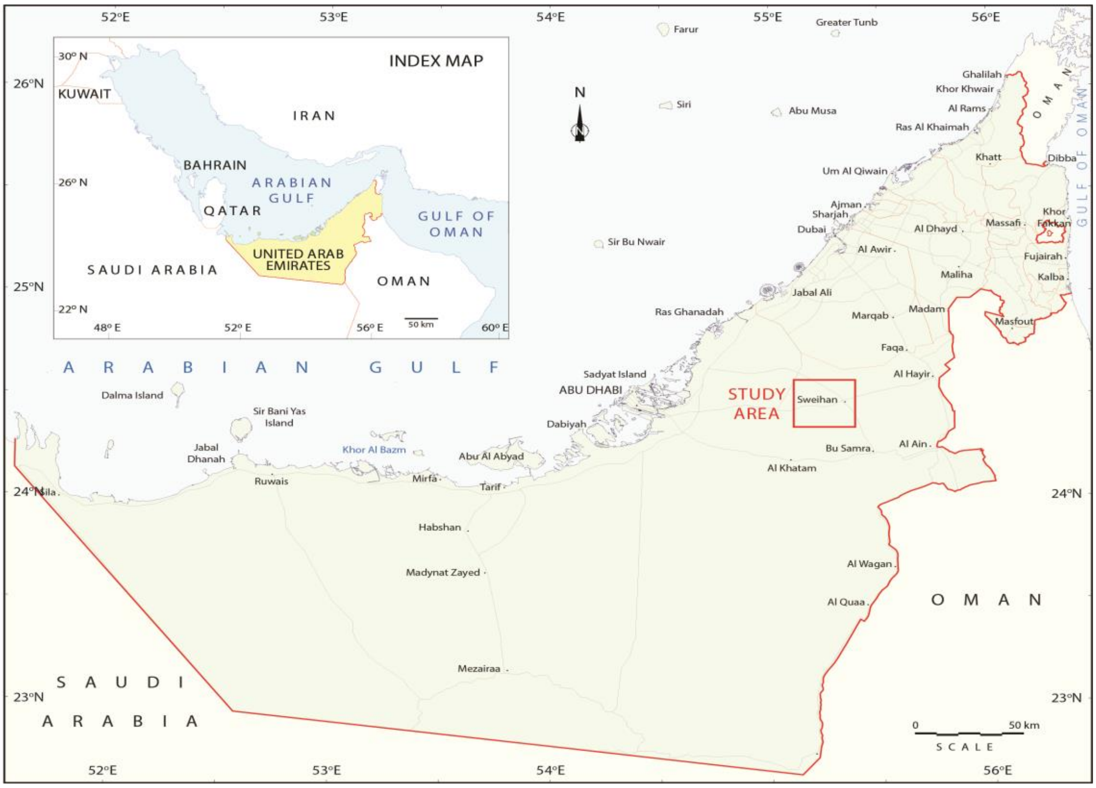

Figure 1: Map shows the location of the study area in Abu Dhabi Emirate

Abu Dhabi is divided geologically into four distinct regions as Abu Dhabi Island, Eastern Region, Western Region, and the Gulf Islands (Ministry of Economy, 2014). Abu Dhabi is geologically dominated by the sand dunes that reach 300 meters high in some areas. The Eastern region is boarded by Hajar Mountains in the East. Hafeet Mountain, which is located South of Al-Ain city have the highest elevation of about 1,160 meters in Abu Dhabi Emirate (Abu-Zied, 2001).

1.2. Climatic Conditions

Abu Dhabi Emirate is located in a sub-tropical dry region. Because the tropic of Cancer runs through its southern part, the Emirate experiences high temperature almost all the year with very hot summer period. Key seasons of Abu Dhabi are summer and winter. Summer season (June to September) is very hot reaching up to 48ºC in the Western region; humidity is high and might reach 69% when getting closer to the coast and lower in south and southwest areas and 75% in the Islands (Abu Dhabi Statistics Center,2014).

Furthermore, temperature in winter ranges from 32ºC during the daytime and 4º C at night. It could reach zero Celsius on some high mountains in Al-Ain (Abu Dhabi Statistics Centre, 2014). Winter season, covering December to March, is affected by the Siberian High Pressure System, which gives the area *Shamal* winds in the North and heavy fog incidences late at night and in the early morning. Autumn, October to November, is not very significant but known to have high winds and frequent fogs. Spring comes on April and May. The extension of a tropical cyclone from the Indian Ocean to the Arabian Gulf results on rain and thunderstorms, and fog as shown in (Figure 2) (Environmental Atlas of Abu Dhabi Emirate, 2011).

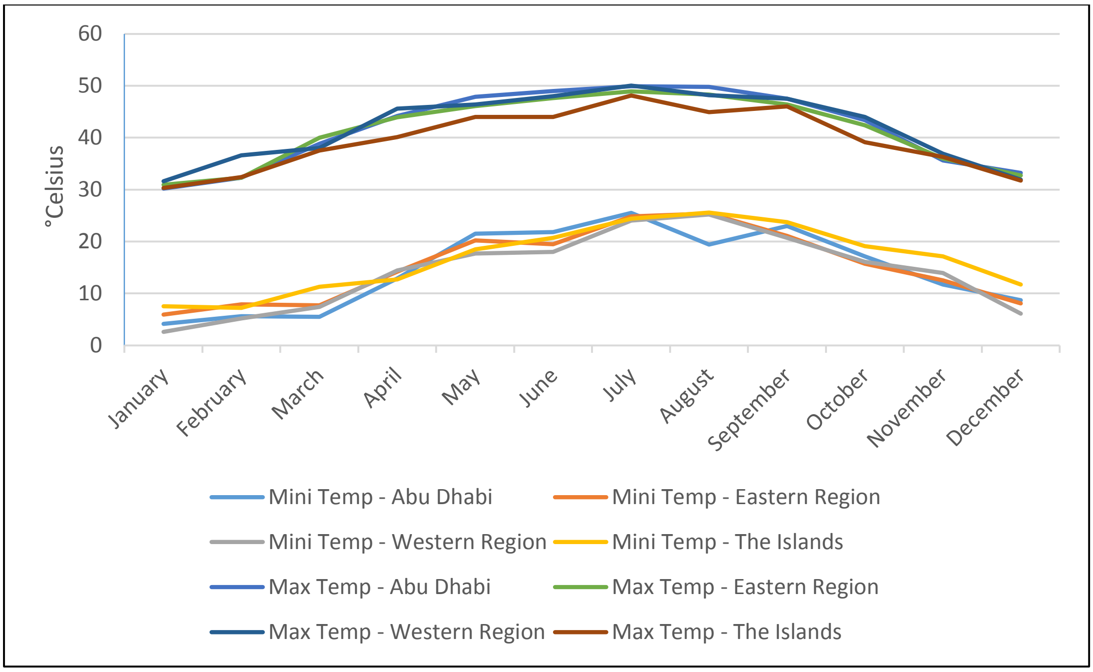

Figure 2: Minimum/Maximum temperatures of Abu Dhabi regions in 2013 (Adapted from ADSC, 2014)

The main two sources of rainfall in the Emirate are the Southwest Monsoon and *Shamal* winds. Between July and December, the SW Monsoon causes rainfall in the eastern part of Abu Dhabi, Al-Ain and the mountainous region. *Shamal* winds are responsible for winter and spring rainfall through the months of December to April (Glennie, 2002). Average rainfall in the Emirate was 77.6 mm in the year 2013. The highest amounts of rainfall occur in November.

Among all regions of the Emirate, Eastern Region tends to have the heaviest precipitation amounts that reach 125.8 mm on November. Although, the western region has less precipitation ranges through all months compared with Al-Ain, it only peaks to 124.2 mm on April (Abu Dhabi Statistics Centre, 2014). (Figure 3) illustrates the precipitation amounts in the year 2013 for Abu Dhabi Emirate.

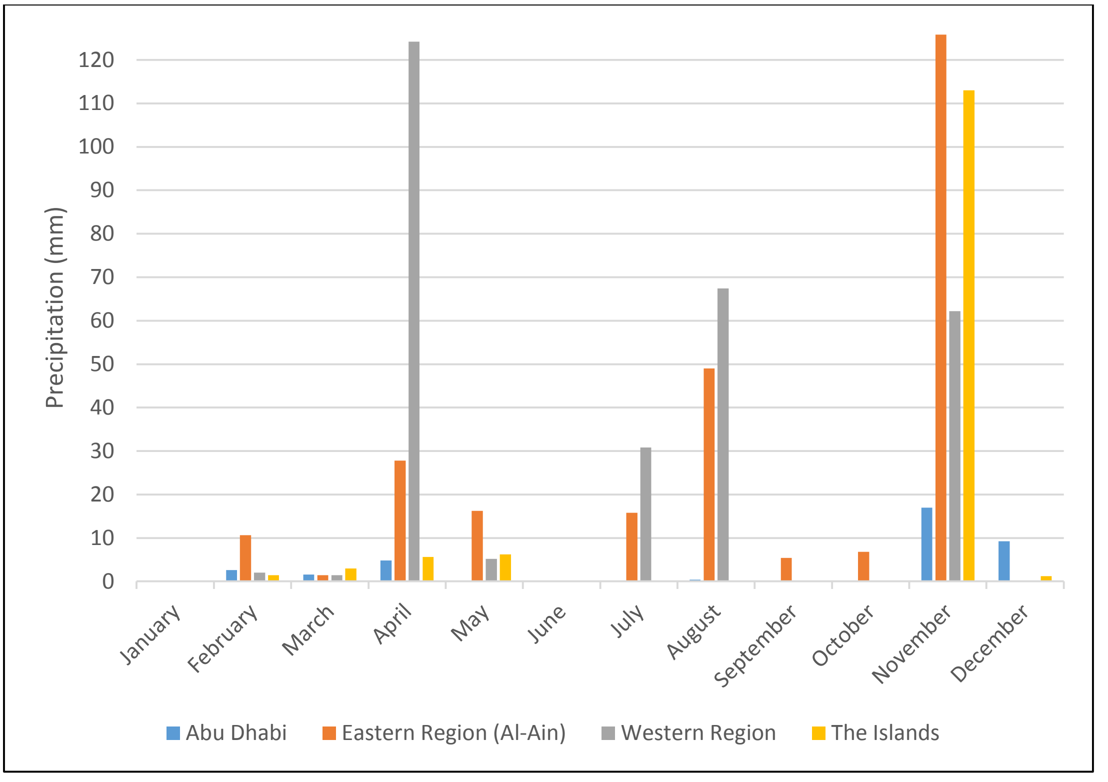

Figure 3: Precipitation in millimeter of Abu Dhabi Emirate regions in 2013

(Adapted from Statistical Year Book, 2014)

Sweihan city is located in the northeast of Abu Dhabi Emirate and northwest of Al Ain city. It is situated in the latitudes 24°28 north and the longitudes of 55°22 east. During summer, temperature reaches from 22.3°C to 50.9°C on June and peaks from 25.3°C as a minimum to 48.1 on September. Humidity is high during the year reaching 11-100% on January. Temperature cools down to 3°C-33°C during winter. Rainfall is rare in Sweihan as it is mostly desert covered with sand dunes. The highest amount of rainfall recorded during the years 2003-2011 was 12mm on January (UAE National Centre of Meteorology & Seismology, 2014).

1.3. Water Resources of Abu Dhabi

Water resources in the UAE are categorized into conventional resources including groundwater and surface water, which is restricted in the Eastern Region only including occasional *wadis* flow, springs and *falajes*. Groundwater is the main water resource in the Emirate, especially in the Eastern Region where the study area is located. On the other hand, non-conventional resources consist of desalination of brackish groundwater and seawater, and treated wastewater (Aquastat, 2008).

Mohamed (2014) shed light on the availability of water resources in Abu Dhabi Emirates; the groundwater accounts for 80% of total water used, while the remain 20% is shared between desalination seawater (17%) and treated wastewater (3%) as illustrated in Figure.4.

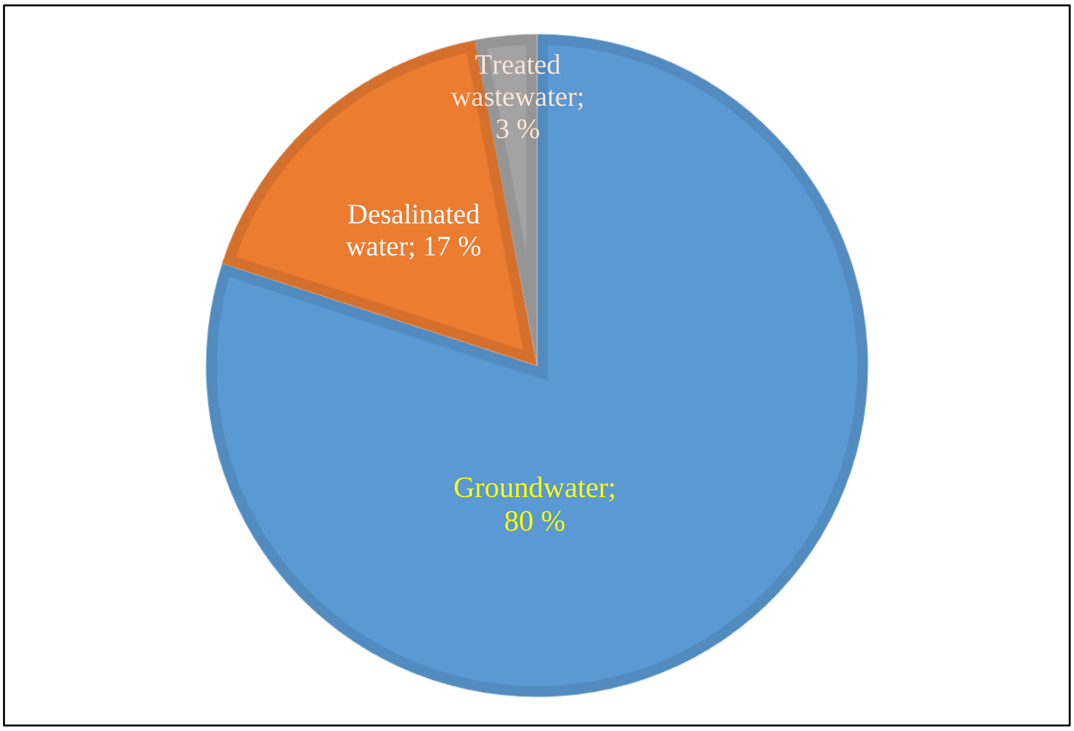

Figure 4: Percentage of different water resources of Abu Dhabi Emirate (Mohamed, 2014)

1.4. Conventional Water Resources

Renewable water resources in Abu Dhabi are limited to groundwater (GW), and surface water including *wadis* flow, some springs and *falajes*. The rainfall is very scarce, random and infrequent, and usually feed aquifers rather than accumulating on the surface. *Falajs* are dry and no longer used. Some springs and *wadis* are present and located in the eastern region of Abu Dhabi (Rizk, 1998).

The annual total demand of Abu Dhabi Emirate was 3.4 billion cubic meters, where 62% of is for groundwater. About 18% of the groundwater is actually used because 3% of it is fresh and 79% is desalinated (EAD, 2012). The average withdrawal of groundwater in Abu Dhabi reached 2,250.9 Mm^3 in 2010, while the average was 2,400 Mm^3 in 2009. Withdrawal of groundwater in Abu Dhabi is being increasing yearly due to heavy pumping of groundwater (Abu Dhabi Statistical Yearbook, 2012). Reserve of groundwater, in contrast, is decreasing over years, which might due to infrequent rainfall and low recharge rates (Osterkamp, 1995).

A summary of groundwater resources reserve for Abu Dhabi on the three different groundwater type on 2010 in mm^3 (EAD, 2011) is illustrated in (Figure 5). Total number of groundwater wells is 40,000 distributed in Al-Ain, central region and western region (Al-Hosani, 2010). Referred to EAD estimations in statistical yearbook 2011, the number of working wells in the whole Emirate is 68,200 wells comparing with 21,800 wells, which are non-active.

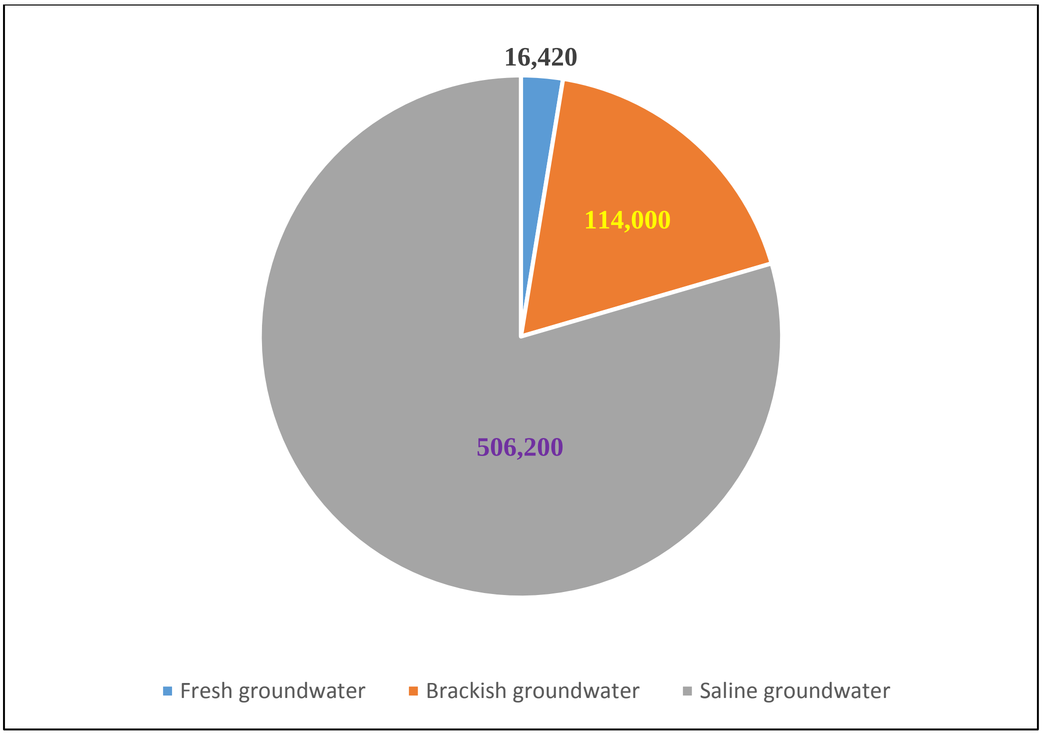

Figure 5: Groundwater reserves by type (mm^3) for Abu Dhabi Emirate in 2010 (EAD, 2011)

Springs are concentrated groundwater that are discharged and flow in the surface ground (Todd, 1980). Springs can have therapeutic values that are rich of sulphur, or fresh springs used for drinking. The only spring that is famous for Abu Dhabi, is *Bu-Sukhanah* spring, which is located in Al Ain city. *Bu Sukhanah* had high discharge records during 1984-1991estimated by 2.50 Mm^3/yr. Rainfall and groundwater circulation systems in Northern Oman Mountains (Rizk, 2003).

The *falaj* is a manmade channel or stream, which intercepts groundwater then brings water to surface by channel without any external influence. *Falajs* are concentrated in Al Ain city, which includes Al-Ain, Al-Daudi, Al-Hili, Muwaiji, Al-Jimi, Mua'tarad and Al-Qattara *falajes* (Alsharhan, 2001). *Wadi* remains dry until rainfall occurs and flows through. When flow becomes heavy and rapid flash floods exists. Flash floods are concentrated in the mountainous eastern region.

The topography of the area and high levels of precipitation caused by Hajar Mountains and Oman's Mountains causes floods to occur. The most environmentally hazardous floods counted for wadi-Shik, Sidr and Ain Al-Faydah in Al Ain (Rizk, 1998). In March 1997, a flush flood occurred in Al-Quaa due to heavy wadi flow in Al-Fatah/Dank catchments. *Wadis* are located between Oman and Abu Dhabi, eastern region, and share 12 main catchments. The total mean annual surface *wadi* that flew in the area was 7.6 mm^3/ year (Dawoud, 2007) as shown in (Table.1).

Catchments Flow within UAE- Abu Dhabi Emirate (Mm3/yr)		
Catchments	*Surface water runoff* (wadi flow)	*Groundwater* (through flow)
Sumayni	0.2	1.4
Safwan	1.5	2.6
Musaydirah Kahal	1.4	1.9
Al Wadiyain	0.6	4.7
Hamad	1.9	1.1
Ajran	0	1
Sifah	0	2.6
Sharri	0	2.3
Al Fatal	2.1	2
Dank	0	7
Sawmahan	0	2.6
Al Hawl	0	1.6
Total	7.6	30.9

Table 1: Catchments flow within UAE- Abu Dhabi Emirate (mm^3/year) (USGS, 1996)

1.5. Non-Conventional Water Resources

Desalination is a process of removing salt and other particulates from seawater, brackish water to make it potable for different human consumption. The first plant established in Abu Dhabi was in 1976 with a capacity of 250 m^3 /day. The amount of the desalinated water then gradually increased as demands for industry and agriculture increased (Rizk, 1999).

Desalination plants have increased to 46 desalination plants concentrated in the coastline of Arabian Gulf and Gulf of Oman. Desalinated water production has raised in 2013 to 1112.12 Mm^3, which increased of about 2.5% compared with 2012. The main large plants in Abu Dhabi are Abu Dhabi, Um Al-Nar, Taweela, Mirfa desalination plants (McDonnell, 2014).

Desalination processes vary in desalination plants. The advanced system used is Thermal Cogeneration producing water and electricity, Multi-Stage Flash (MSF) distillation and Multi-Effect Distillation (MFD). Other plants are using Reverse Osmosis (RO) system but not common in use. Thermal Cogeneration plants accounts for 93% of the total desalination capacity in Abu Dhabi Emirate in 2011(Assaf, 2014).

Abu Dhabi consumption of desalination water differs from sector to another and from region to another does. The total consumption of desalinated water in the year 2013 was 1082.4 Mm^3. The consumption of desalinated water was in the year 2013 by percentage as the following, Abu Dhabi city 61%, Eastern Region 27% and Western Region 12% (Abu Dhabi Statistical Yearbook, 2014). Figure.6 illustrates the percentage of different desalination systems of the total capacity in Abu Dhabi Emirate in 2014.

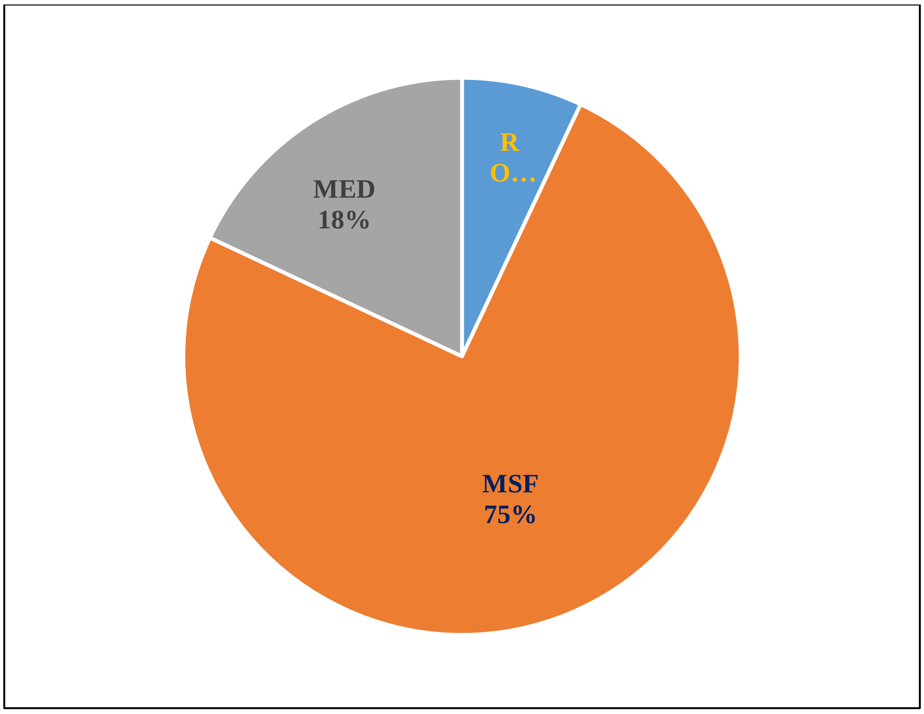

Figure 6: Desalination percentage of each system in Abu Dhabi in 2011 (Assaf, 2014)

Both industry and commerce sectors have come to be the heavy-used consumers of the desalinated water. The public sector, domestic and agricultural consumption is the next. On the other hand, the main consuming sector in Eastern Region is the agriculture followed by the domestic and public utilities, whereas in the Western Region, the main consuming sector is the government followed by the domestic and commercial. (Figure 7) illustrates the consumption of the desalinated water by various sectors at the different regions of Abu Dhabi Emirate (Abu Dhabi & Al Ain Distribution Company, 2014).

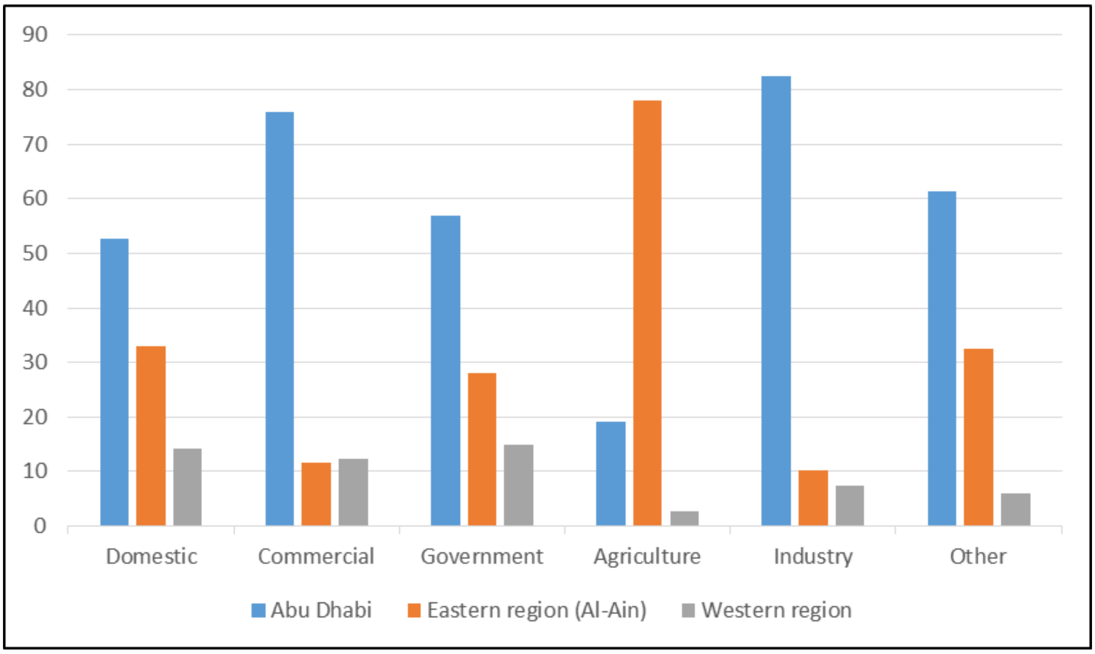

Figure 7: Percentage of desalinated water consumption by regions & sectors in 2011

Treated wastewater is the other non-conventional source used in the Emirate. In 1980s, the idea of reusing wastewater after treatment was introduced to meet some of the demands in the Emirate (Al-Zubari, 1998). The amounts of treated wastewater are increasing due to high economical and developmental standards. The production of treated and reused wastewater has increased in 2013 reaching 283 mm^3.

Abu Dhabi Island produces 74% of the total production, Eastern Region produces about 41% and Western Region has the least production percentage of 5% (ADSSC, 2014). There are 28 sewage treatment plants are now operating; the largest are Zakher and Mafraq plants. The main uses of wastewater are in irrigating parks, roadsides and golf courses, fodder crop irrigation and highways landscaping (McDonnell, 2014).

1.6. Statement of the Research Problem

Sustainability of groundwater in the Emirate is facing a catalogue of serious threats, which could affect the availability of water resources as a whole. Those threats include groundwater depletion and continuous deterioration with rainfall scarcity and inadequate levels of management. Water level is decreasing due to high rates of consumption, heavy pumping practices and limited amount of recharge (FEA, 2002).

As the population increases and the per capita living standards increases, the demand of water increases which put more stress on groundwater and leaves a gap between supply and demand (EAD, 2009). The highest amount of groundwater is consumed by agriculture sector, which accounts for 69% of the total water consumption. The cultivated areas are concentrated in southeast and Eastern Region of Abu Dhabi Emirate (Mohamed, 2006). The total cultivated area has reached to 752,839 donums (one donum = 1000m^2) in 2013 in Abu Dhabi Emirate (ADFCA, 2014).

The systems that are used in the Emirate generally for irrigation are sprinkler, localized irrigation, and basin and furrow for surface irrigation (Aquastat, 2008). The total cultivated land occupies 752,839 donums, producing a variety of crops, fruits, vegetables and windbreaks. Rhodes and palm trees are on the top of water consumers in the field. Several farms are going out of production because of lack of water supply, especially in the Eastern Region (ADFCA, 2012). Wrong practices from unaware workers in disposing wastewater from farms and industries and overuse of fertilizers could contaminate the groundwater and change its suitability for human consumption (Mohamed, 2006).

The salinity is increasing due to heavy use of groundwater and low recharge. Salinity of groundwater in Abu Dhabi Emirate ranges from 1,500 mg/l - 125,000 mg/l (Environmental Atlas of Abu Dhabi, 2011). Another issue is the imbalance between the recharge and discharge, which has led to dramatic depletion to the water table in groundwater zones. In 2005, groundwater used where reduced to 18% comparing to 2003 (10%) due to aquifer depletion (EAD, 2006).

Sweihan region is located in the northeast of Abu Dhabi and northwest of Al-Ain City. Sweihan cultivated area estimated was 11,156 donums of 275 farms in 2011 and covered 2% of total cultivated area in the Eastern Region. Only 270 farms with an area of 11,002 donums are working while the remaining five farms are not active. There are number of different crops recorded in the area.

Field crops of *rhodes*, *alfalfa* and dates comes on the first order of production in the area, followed by fruit crops including banana, cider fruit, mango, lemon, figs, pomegranate, orange, *murus alba* and grapes. Vegetables are also cultivated such as tomato and cucumber. Moreover, forest tree is widespread in the area including Ghaf and Cider (ADFCA Statistics Book, 2011).

The main water source used for irrigation and domestic is groundwater. According to ADFCA (2011), number of wells in Sweihan was 1317 where 786 are working wells with an average depth of 400 meters. Recently, groundwater has been depleted in the area, and farmers are complaining of not getting enough amounts of water for their crops. Many farms are not operating because of water shortage. As well as, the quality of water is not good enough for irrigation.

After meeting a group of farmers in the region, and according to field research of 508 groundwater samples in Al Ain and the surrounding cities including Sweihan conducted by Al-Salamat Laboratory in Sweihan (ADFCA, 2005), the area was suffering from high concentrations of nitrate that ranged from 3-70 mg/l and salinity that ranged from 1,904 to 13,090 mg/l.

According to Bollaci et al (2010), high concentrations of heavy metals and pollutants coming from fertilizers in particular, such as chromium, boron and fluoride were noticed. In addition, 80% of these samples contained amounts of nitrates that exceeded WHO standards. High concentrations of pollutants cause economic and public health challenges. Not only it becomes a health hazard for human consumption, but also it has an effect on agriculture and natural vegetation in the area.

1.7. Objectives

The study aims to assess the groundwater quality chemically by using major anions and cations and trace elements especially heavy metals in the region of Sweihan, northeast of Abu Dhabi Emirate. Moreover, the study focuses on the main factors that affect the quality of groundwater in the study area. In addition, the study provides a clear evaluation of the availability of using the groundwater of the region for domestic and irrigation purposes. The isotope analysis will evaluate the factors affecting the groundwater quality and recharge mechanisms in the study area.

CHAPTER TWO

GEOLOGY AND HYDROGEOLOGY OF SWIEHAN

2.1. Introduction

The Sweihan is located west of Al-Ain city and east of Abu Dhabi capital connected by road network with neighbour areas. The study area lies at latitude 24°28 N; longitude 55°22 E; its elevation approximately 150 meter above sea level (Figure. 8).

Figure 8: Aerial view of Swiehan area

On the other hand, Sweihan area considered as a typical desert aridland, characterized with sand dunes separated by lower lying inter-dune areas. Sweihan region is a famous for agriculture, mostly private farms with high production rates. Most farms are suited between dune ridges. Natural vegetation is generally sparse, though the study area and has higher rainfall rates than the western desert region.

The below field photos as shown in (Figure 9) describing the following geological features of the Sweihan study area:

a) The dunes in the study area.

b) Inter-dune areas covered with natural vegetation.

c) Conglomerate layer in the study area.

d) Inter-dune areas without natural vegetation.

e) Close up view for the conglomerate layer.

f) Farms in the study area.

g) Sand dunes in the study area.

h) Internal dunes in the study area

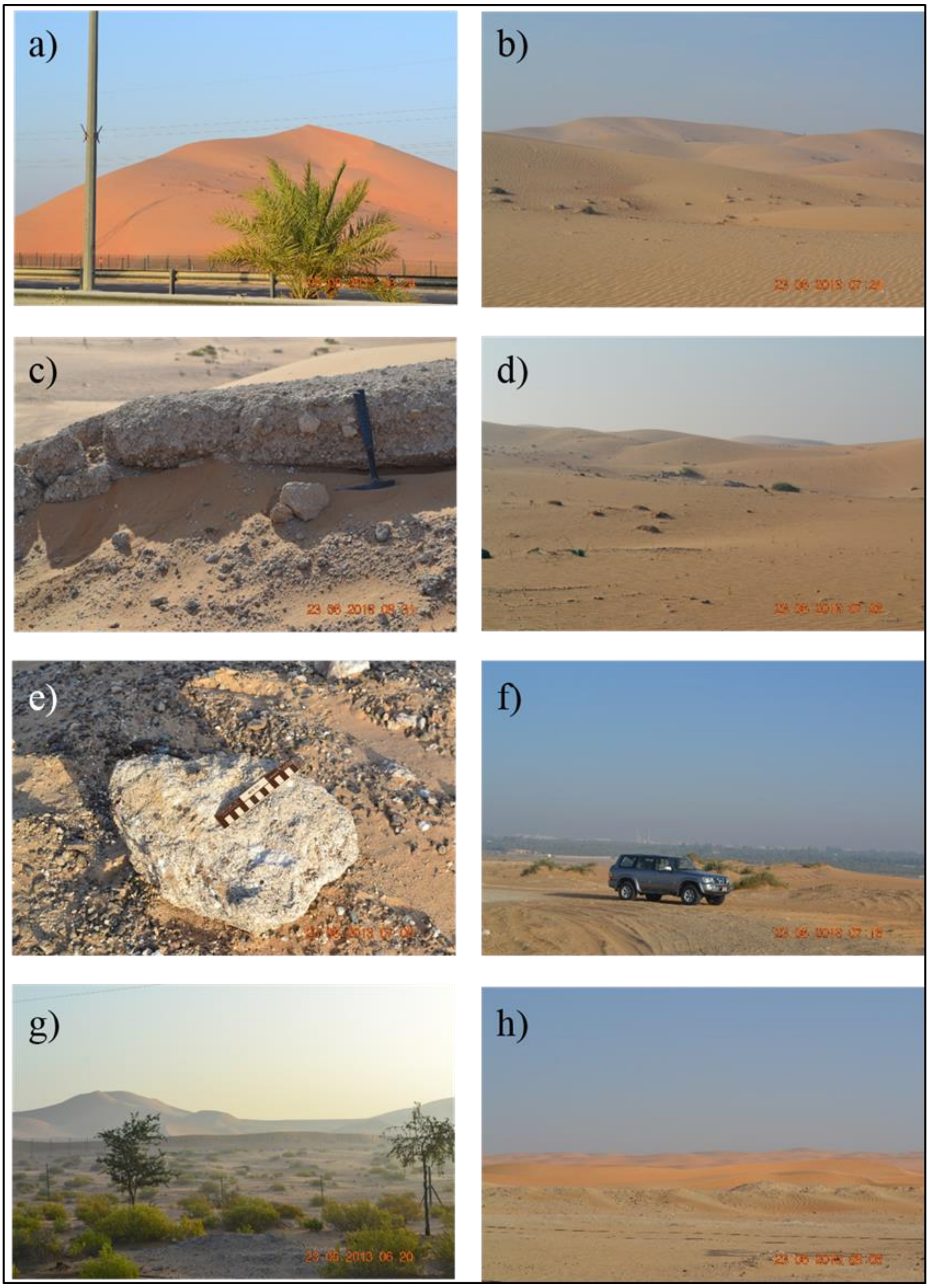

Figure 9: Field photos of the study area

2.2 Geology of Swiehan Area

Few field studies have been published on the geology of the Sweihan area, e.g. Ahmed et al. (1998), Alsharhan et al. (1998) and Abu-Zeid et al. (2001). The latter studies concentrated on the sedimentology of the dunes and inter-dune areas.

Those studies concluded that the Sweihan dunes and inter-dunes were accumulations of well-sorted fine sands that consisted mainly of quartz and carbonate grains, with small amounts of chert, feldspars and heavy minerals similar to those present in rocks of the Zagros and Hajar Mountains. Hunting (1979) noted that the sand grains of the Emirates desert areas consist of well-rounded carbonates and quartz with minor proportions of mafic and ultramafic igneous rock fragments.

2.2.1. Lithostratigraphy of Tertiary Rocks

The Tertiary age bedrock units are described below from oldest to youngest. These geological features of Sweihan area were detailed (as shown in Figure 10 and Figure 11) by Thomas et al. (2012).

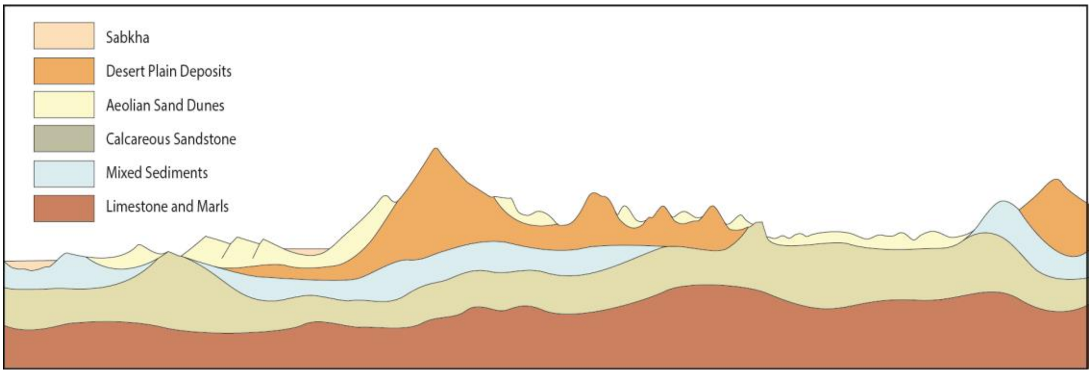

Figure 10: Schematic cross section of the study area

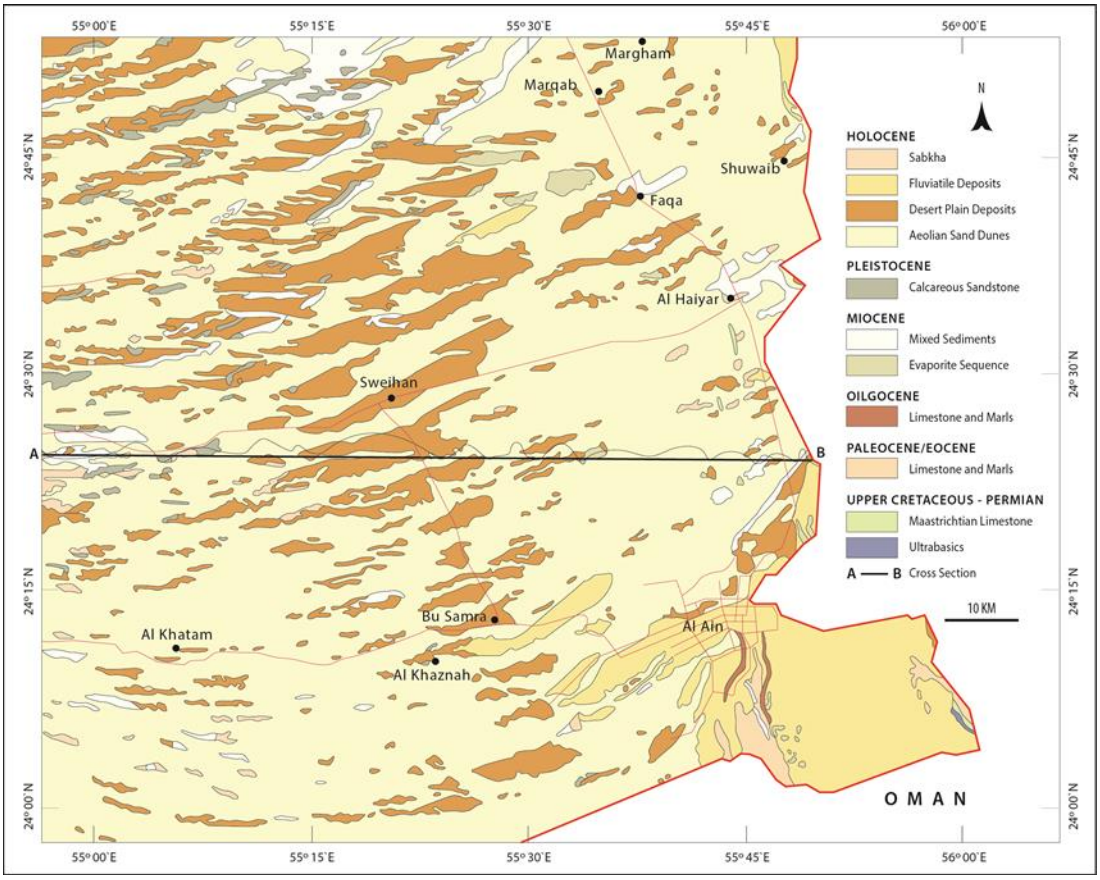

Figure 11: Geological map showing the topography of the study area

The Tertiary geological features are demonstrated in the following geological formations:

1) ***Barzaman Formation of Middle Miocene to Pliocene Age*** – this formation consists of mainly well-cemented polymictic conglomerates. It was deposited on fluvial fan deposits that debouched from the Hajar Mountains.

2) ***Hili Formation*** is widely distributed in the Sweihan area, with best exposures in the inter-dune areas where it overlies the Barzaman Formation. It consists of quartz-rich conglomerates, pebbly sandstone, sandstone, siltstone and mudstone. It represents inter-bedded fluvial and aeolian deposits that were transported from provenance areas in the Hajar Mountains. The

sediments of the Hili Formation are distinguished from those of Barzaman Formation by the matrix, which contains brown sand, gravels and grits, while the Barmazan sediments contain white dolomite fragments.

2.2.2. Quaternary

The bedrock of the Sweihan area is broadly covered by Quaternary sediments. These sediments vary in colour from red and pink to white and include mainly aeolian sands heaped into dunes and aeolianite deposits as shown previously in Figure 9. These sediments principally derived from earlier reworked Quaternary aeolian, marine and fluvial deposits to contain a mixture of carbonate and siliciclastic material.

Probably, the concerned sediments had been transported from neighbouring areas as Saudi Arabia, Iraq and Iran; among these formations were:

1) ***Ghayathi Formation*** is exposed in the northwest of the area, and composed of pale cream-colored carbonate aeolianite. It overlies the Hili Formation. The bedrock of the Sweihan area is broadly covered by Quaternary sediments. These sediments vary in colour from red and pink to white and include mainly aeolian sands heaped into dunes and aeolianite deposits (Figure 9). The sediments were principally derived from earlier, reworked Quaternary aeolian, marine and fluvial deposits, and contain a mixture of carbonate and siliciclastic material, probably transported from as far away as Saudi Arabia, Iraq and Iran.
2) ***Dune ridges*** are present in the Sweihan area and describe a broad arcuate pattern across the east-southeast, west to west-southeast/east-northeast in the

east. The ridges can reach a maximum width of 2 Km, and a height of 30 m above the surrounding inter-dune areas.

3) ***Sabkha*** *was* formed when wind erosion deflated the ground surface down to a level just above water table, and within the capillary zones. Sulphate-rich groundwater brines evaporated allowing the formation of gypsum in the superficial sediments or bedrock that underlies the inter-dune areas. Sabkha layers are distributed in small inter-dune areas especially in the northwest of the study area. The Sabkha lie above Barzaman, Hili and Ghayathi Formations. In some areas, Sabkha are active, particularly where the water table is very close or just above the ground surface, leading to gypsum deposition from saturated brines and local colonization by green algal masses.

2.3. Sweihan Hydrology

Aquifers of Sweihan are mostly shallow with a maximum depth of 50 meters. The depth increases continuously due to heavy pumping of groundwater for agriculture and other purposes. Nowadays, the depth could reach 500 meters. The aquifers are thick reaching 40-50 meters and salinity of 1,500 – 10,000 mg/l (Environmental Atlas, 2011; Garamon, 1996).

On the other hand, about 80% of aquifers in the UAE are quaternary sand and sand with gravel aquifers. Sweihan aquifers are unconsolidated shallow deposit and considered one of the productive aquifers in the Emirate. Aquifers are quaternary sand and gravel aquifers underlain by the Upper Fars Formation as basal unit comprising early Miocene age, mudstones and marly dolomites (GTZ et al, 2005).

The UAE aquifers are categorized into three flow types, which are local, intermediate and regional. Groundwater moves from East to west for all flow types.

Sweihan aquifers are considered regional flow type. Regional aquifers have slow movements with long residence groundwater system. Moreover, the main hydrochemical characteristics for regional flow type are high temperature rate and high-mineralized groundwater, and long recharge time reaching 15,000 years. As the aquifer has long residence time, it results in accumulation of salt in the aquifer and dissolution of salts in groundwater. Sweihan shallow aquifers are considered as chloride type aquifers (Brook, 2006).

The lithology of Sweihan aquifers are, in general, marly nature that covered by clay and gypsum in some area, then there are some conglomerate and dolomite rocks, but mostly gravel, covered by sand at the top. Most of the sands covered are fine to medium fine and loose sand type. The upper parts of the aquifer have moderate permeability and high porosity underlying by gravel and conglomerates, decreases with increasing depth (EAD, 2012).

CHAPTER THREE

METHODOLOGY

3.1. Materials

To meet the objectives, water samples were collected from the study area, measured in the field using physical parameters, and stored in permeable way. Samples were tested for anions, cations and trace elements at UAEU laboratories. In addition to that, isotopes analysis was also performed. Precautions and controls were taken before and during the entire measurements.

3.2. Sampling

Sampling has taken place in January 2010. About 27 groundwater samples were collected systematically from different wells using two pathways, from north to south and from east to west in the study area as shown in (Figure 12).

From each well, two bottles of samples were collected; each with a volume of 1 litre. For major cations and heavy metals samples was acidified with nitric acid (HNO_3 65%). Samples in the laboratory are preserved at cool temperature of 4ºC. Additional 15 groundwater samples with 20 ml each were collected for hydrogen and oxygen analysis in glass tubes with V-shape plastic cap to prevent evaporation. Bottles were transported and stored in cold container (< 4ºC).

3.3. Field Measurements

Collected groundwater samples were measured in the field for pH (H^+ ion concentration) using pH meter. Temperature (°C), electrical conductivity (EC), and total dissolved solids (TDS); salinity were performed in the field using Hanna Instrument (HI9828). GPS (Garmin-Montana650) employed in positioning locations; *AquaChem*™ software used for graphical presentation and *Surfer Manipulation*™ software for the maps presentation by *Inverse Distance Weighting* method.

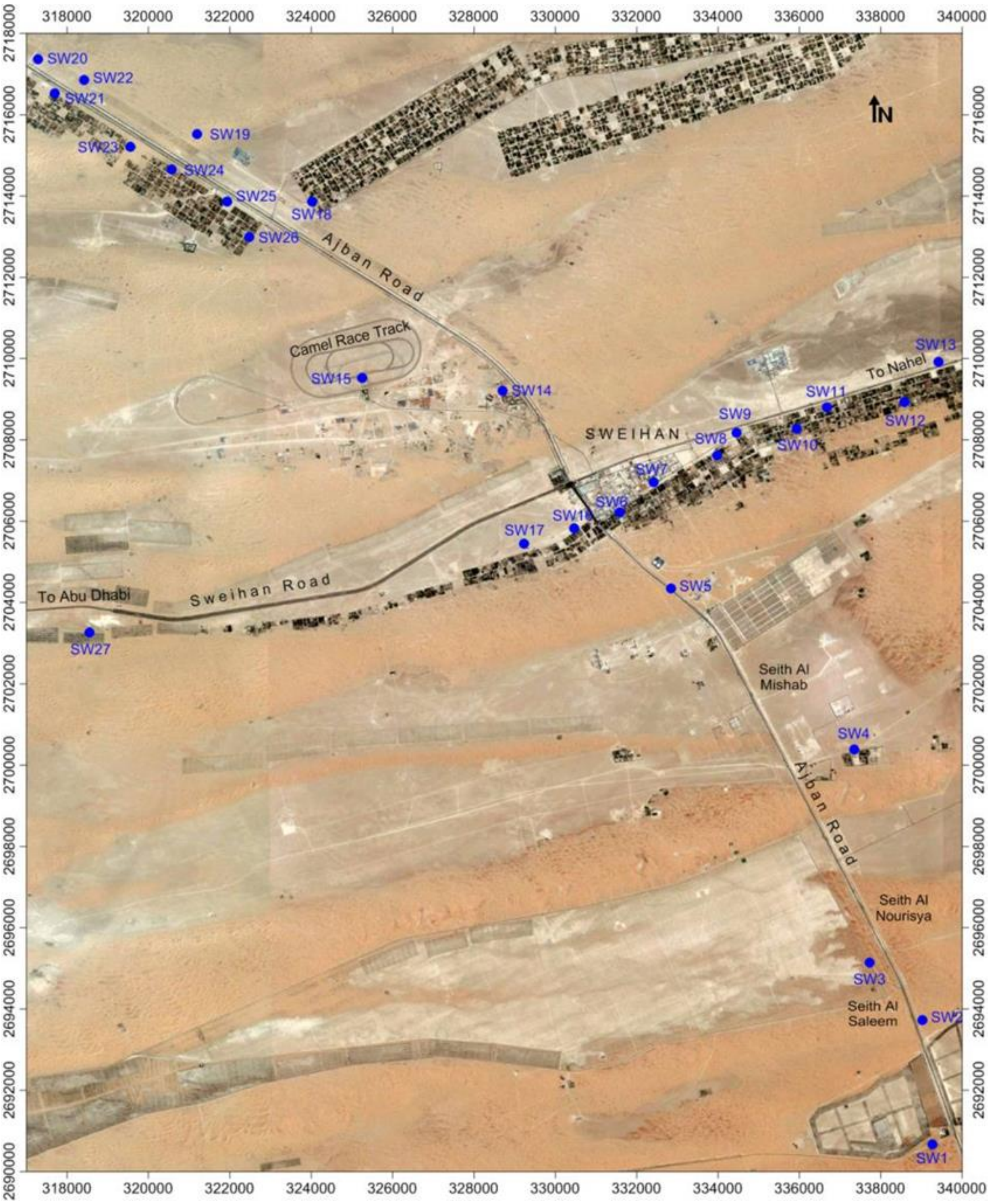

Figure 12: Satellite map shows the location of the GW samples collection in Sweihan

3.4. Laboratory Measurements

Water samples were analysed for anions, cations and trace elements. Anions including NO_3^-, NO_2^-, SO_4^{-2}, HCO_3^-, Cl^-, and PO_4^-, were detected in the samples using Ion Chromatography (IC) (Dionex ICS-2000). Anions' testing was performed in the Chemistry Laboratory at UAE University. For cations including Na^+, Mg^{+2}, K^+, Ca^{+2}, and trace elements including Pb, Ba, Cr, Cd, As, Mn, F, Fe, Sr, Ni, Al, Co, Inductively Coupled Plasma Mass Spectrometry (ICP-MS) (Varian 715-ES) was used to determine the elements present in the samples especially heavy metals and quantify their concentrations. Measurements were done in mg/l in the Geology Laboratory at the UAE University. All instruments are listed in Plate 1.

For quality control, all glassware used in the measurements cleaned, rinsed with water, 1% nitric acid and deionized water prior to next use. Samples with high dissolved solids are diluted to ensure correct results, as they have different viscosity and nebulation rate than the standards. Proper care is taken in the preparation and storage to avoid contamination (EMSL, *Method 200.7*).

3.5. Stable Hydrogen and Oxygen Isotopes

Fifteen groundwater samples were collected for hydrogen and oxygen isotopes analyses. About 20 ml of water samples were stored in sealed airtight glass bottles. The collected samples were analysed using a laser evaporation-based mass spectrometry at the Centre for Ice and Climate in University of Copenhagen, Denmark. The data was reported in the usual δ notation with respect to the *Vienna Standard Mean Ocean Water* (VSMOW). The precision for $\delta^{18}O$ is 0.1-0.2 per mil and for δD it is 0.5-1.0 per mil.

Hanna Instrument (9828) Ion Chromatography (Dionex ICS-2000)

Inductively Coupled Plasma Mass Spectrometry (Varian 715-ES)

Plate 1: The instruments used in the field and laboratory measurements

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. Physical Properties

Physical properties are important in determining the quality and acceptability of groundwater in a certain area. The parameters used in studying the quality of groundwater in the study area are temperature, hydrogen ion concentration (pH), electrical conductivity (EC), and total dissolved solids (TDS). Below is a detailed discussion about the results of those parameters in the study area.

4.1.1. Temperature

Temperature of the aquifer plays a critical role in physical and chemical behaviour of the water system. The range of temperature of Sweihan groundwater samples is from 29.2 to 32.5 °C. These high temperature values indicate an arid region with low rainfall and low recharge level (Murad, 2011). The temperature is increasing toward the northeast and northwest of Sweihan and cooling down in the centre and the south as shown in (Figure 13).

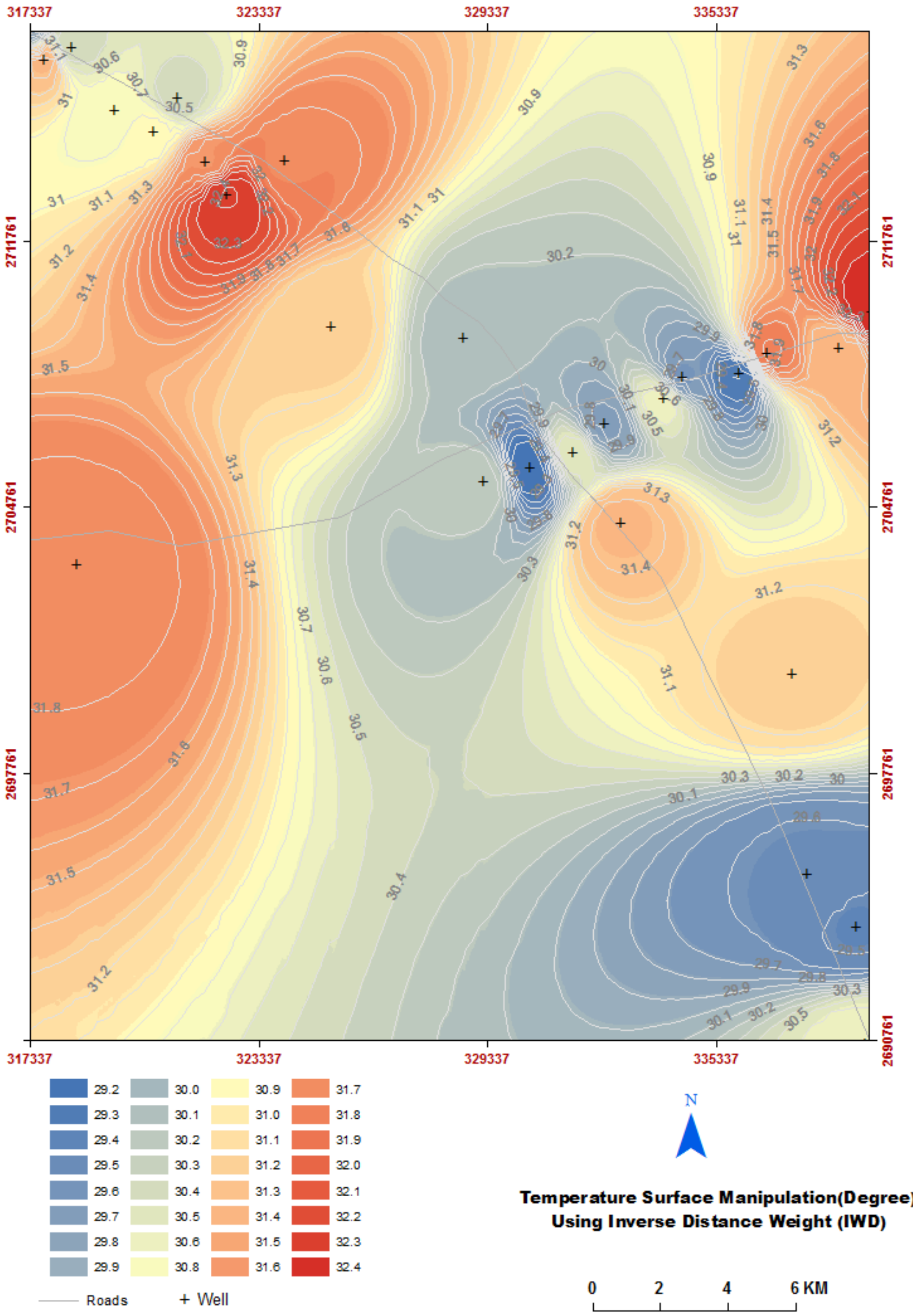

Figure 13: Contour map shows temp. distribution of GW samples in study area

4.1.2. Hydrogen Ion Concentration (pH)

The pH is one of the most common water quality indicators for testing the sample's acidity. It is actually a measurement of the potential activity of hydrogen ions (H^+) in the sample. The pH measurements have a scale from 0 to 14, where 7 considered a neutral. Solutions with pH below 7.0 are considered as acidic nature, while solutions with a pH above 7 up to 14 are considered basic nature or alkaline (WHO, 2003).

The pH of water is influenced by many factors; among the most common are the bedrock and soil composition, which the water gets in contact with it. Other factors may be the amount of plant growth and organic materials in the flow (Oram, 2014). Hydrogen ions are such small molecules that easily enter the mineral structures and change the amount of some dissolved components in groundwater.

In other words, the more availability of hydrogen ions in water (greater the value), the lower the pH, which means more acidic, the higher the Total Dissolved solids (TDS) as a result of high bicarbonate presence HCO_3 deriving originally from a reaction of water molecules (H_2O) and the abundance of CO_2 in the atmosphere (Nelson, 2002). In relation with TDS, pH is slightly basic where TDS is at low amounts (south and southeast), and the high TDS in the northwest, the more pH becomes neutral. According to World Health Organization guidelines, (WHO, 2011) pH less than 6.5 or greater than 9.2 impairs the portability of the groundwater for drinking purposes.

In addition, pH usually has no direct impact on human health if stays around the neutral value. The pH values for groundwater samples in Sweihan are within the permissible limits. The pH values for groundwater in the study area are varied from 7.2 to 8.9. The pH is more neutral in the centre of the study area and becomes more alkaline toward the southeast as shown in (Figure 14).

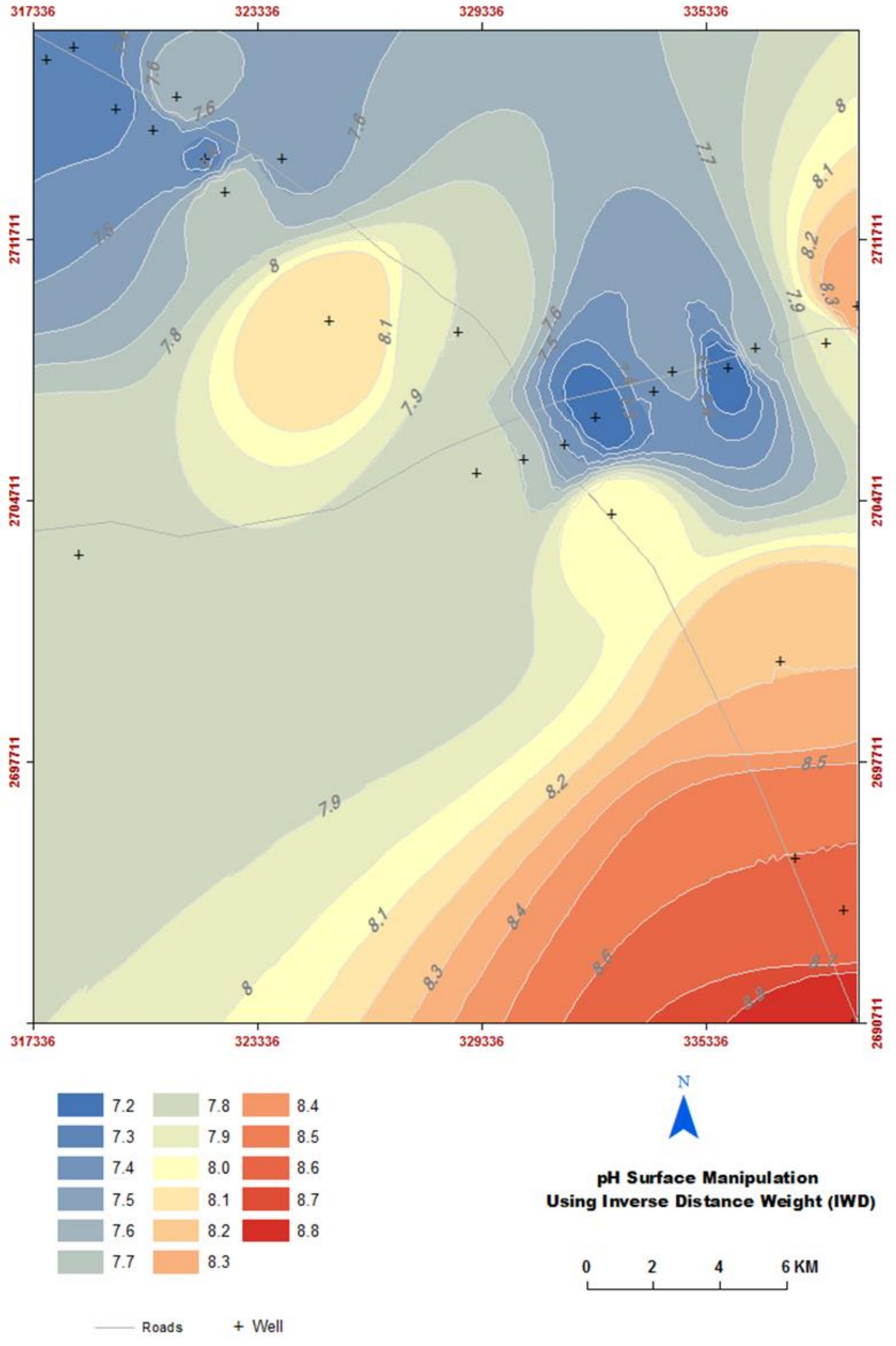

Figure 14: Contour map of the pH distribution of GW samples in the study area

In relation with TDS, pH is slightly basic where TDS is at low amounts (south and southeast), and the high TDS in the northwest, the more pH becomes neutral. According to World Health Organization (WHO, 2011) guidelines, pH less than 6.5 or greater than 9.2 impairs the portability of the groundwater for human drinking purposes. In addition, pH usually has no direct impact on human health if stays around the neutral value. The pH values for groundwater samples in Sweihan are within the permissible limits.

4.1.3. Electrical Conductivity (EC)

Electrical Conductivity (EC) expresses the concentration of ionized substances in water. The maximum permissible concentration of EC for drinking water according to WHO is 1400 µS/cm (WHO, 2011). The electrical conductance is a measurement of total ionic concentrations in the water at a standard temperature of 25°C, which allows the electricity to go through (Todd, 1980). Sweihan samples showed values varied from 4590 µS/cm to 25,600 µS/cm as the highest value of the sample No. 24. As shown in Figure 15, the EC high values are concentrated in the west, especially northwest of the region.

The EC is an essential factor in determining the quality of water. According to the values measured, Sweihan groundwater is not suitable for drinking, as the EC exceeded the permissible limit of the WHO (Gupta, 2009). The EC is related directly to total dissolved solids present in the water. If dissolved solids increase in the water, the EC increases as the presence of cations and anions causes increases of conducted electricity. High amounts of TDS present in the sample are the core reason of having high EC amounts in Sweihan samples (Harter, 2003). TDS will be discussed in details in the next paragraph.

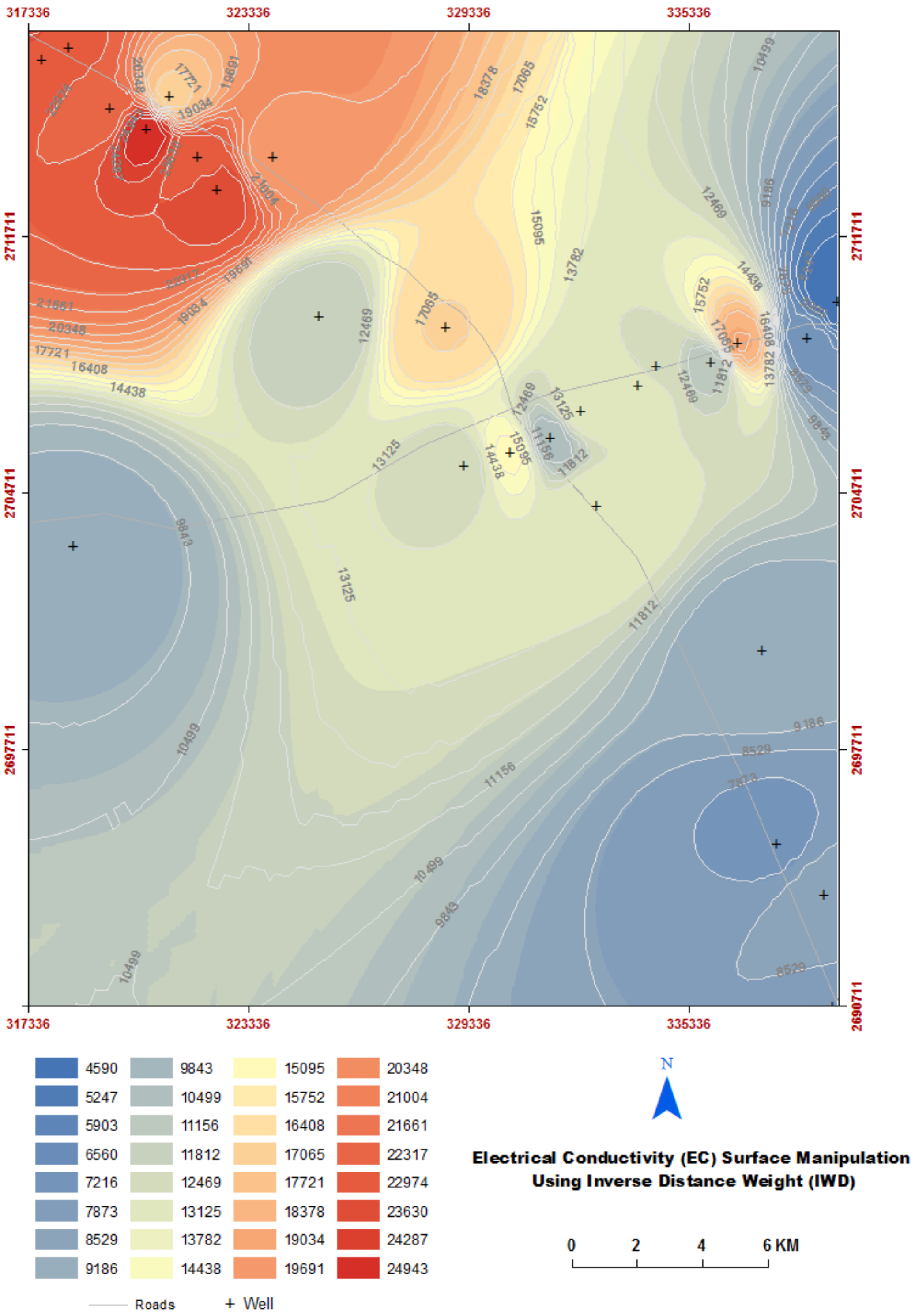

Figure 15: Contour map of the EC distribution of GW samples in the study area

4.1.4. Total Dissolved Solids (TDS)

Total dissolved solids (TDS) are one of the geochemical parameters used to evaluate groundwater quality. TDS are matters that stay in water after evaporation and accumulate after dryness. They are inorganic salts such as calcium, magnesium, potassium, sodium, bicarbonates, chlorides and sulphates, and small amounts of organic matters that are dissolved in water (Harter, 2003).

In addition, TDS can originate from natural sources such as minerals weathering from rocks, sewage effluents, agricultural runoff and industrial wastewater (Chilton, 1996). Regarding WHO standards, concentration of TDS in the water should not exceed 100 mg/l to be potable for drinking purposes (WHO, 2011). The TDSs consist of ionic salts, which conduct electricity to indicating a general nature of salinity in the water, and related to total electrical conductivity. Water with high TDS have salty taste and produce scales on cooking vessels and boilers, water pipes, household appliances. However, TDS is not recorded to have any adverse effect on human health (Etekwana, 2004).

In Sweihan samples, the TDS ranges from 2,938 to 16,384 mg/l. High values are concentrated heavily in the northwest reaching 16384 mg/l in sample No.24 and decreasing toward the east and southeast. Regarding the WHO standards, all samples in the study area exceeded the permissible limit of 1000 mg/l. The high concentration of TDS is correlated to the presence of ionic salts, which are sodium, potassium, magnesium, calcium and chloride.

These ionic salts are present from natural sources from precipitation and evaporation processes. As well, dissolution of minerals from sedimentary rocks present in the study area contributes to TDS accumulations, which are gypsum, dolomite, feldspars, and chert (Saskatchewan Government, 2008). Furthermore, different agriculture activities such as using of fertilizers and leaching of agriculture runoff into groundwater are also a main reason of having TDS in the groundwater (Thiros, 2010).

Elangovan (2009) referred to TDS ranges regarding their use for drinking and irrigation. According to his classification <500 mg/l is desirable for drinking, 500-1000 mg/l is permissible for drinking, 100-3000 is useful for irrigation, and >3000 considered unfit for either drinking or irrigation. With comparison to his classification, TDS ranges of Sweihan samples are not suitable for drinking or irrigation as it exceeds 3000 except for sample No.14 (2938 mg/l).

Comparing results of the study with other previous studies regarding TDS, a hydrochemical assessment of Sweihan area concluded that TDS and EC values of collected groundwater samples exceeded the WHO limit. The assessment suggested that high EC values could be due to the increase amounts of anions and cations especially sodium and chloride in the groundwater (ADFCA, 2005).

Another Study near Sweihan area was done by National Drilling Company, concluded that samples studied reached on TDS a value of 10,000 mg/l, while 15,000 µS/cm for EC. These values are considered not potable for drinking. Therefore, groundwater needs to be treated by removing the accumulated salts and then used for irrigation (Imes, 2009). Figure 16 represents a contour map of the TDS distribution of groundwater samples in the study area.

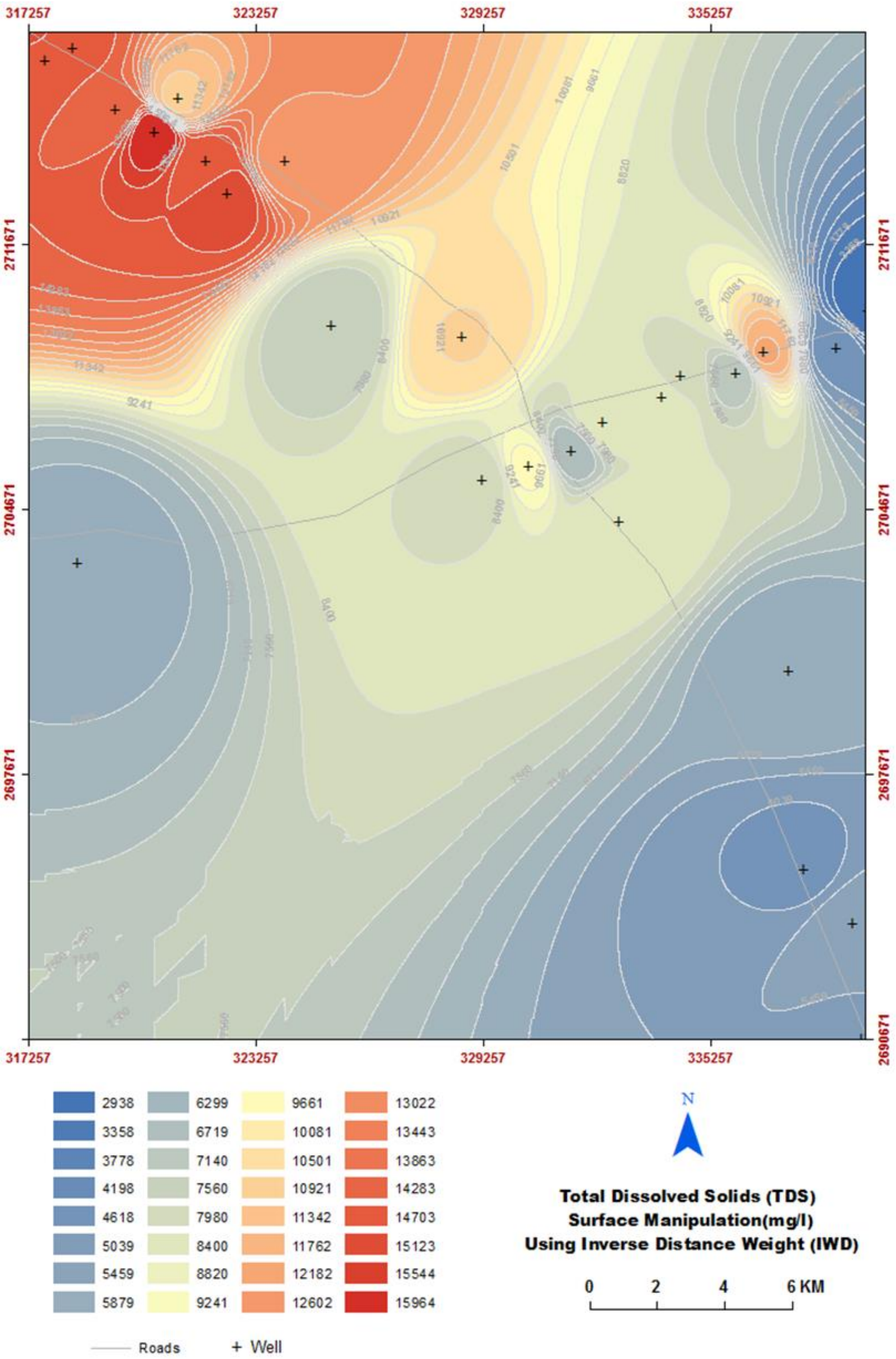

Figure 16: Contour map of the TDS distribution of GW samples in the study area

4.2. Chemical Properties

The chemical composition of groundwater is influenced by the type and amount of soluble of rock weathering and decomposition. The main parameters measured to use in analysing water quality, are cations including Ca^{+2}, Mg^{+2}, Na^{+}, K^{+}, and anions including Cl^{-}, SO_4^{-2}, HCO_3^{-}, NO_3^{-}, NO_2^{-}, and PO_4^{-2}. Other trace elements were measured as well including Pb, Ba, Cr, Cd, Co, Mn, F, Fe, Sr, Ni, and Al. All the chemical species resulted in the analysis of study area groundwater are presented in (Table 2).

Table 2: Chemical species of study area GW analysis

Sample ID	X	Y	pH	Temp (°C)	EC (µS/cm)	TDS (mg/l)	Na (mg/l)	Ca (mg/l)	Mg (mg/l)	K (mg/l)	Cl (mg/l)	$SO_4^{=}$ (mg/l)	HCO_3^- (mg/l)	NO3 (mg/l)	NO2 (mg/l)	PO4 (mg/l)	Al (mg/l)	Ba (mg/l)	Cd (mg/l)	Co (mg/l)	Cr (mg/l)	Fe (mg/l)	Mn (mg/l)	Ni (mg/l)	Pb (mg/l)	Sr (mg/l)
SW1	2690671	339272	7.93	30.7	8470	2938	1884.96	160.268	103.074	28.701	2023.5	1900.8	52	15.2	0.9	0	0.02	0.010	0.001	0.002	0.133	0.017	0.009	0.003	0.011	6.024
SW2	2693735	339021	7.71	29.5	8990	4851	2341.33	159.835	130.824	29.855	1917	3321.6	31	12.5	0.5	0.1277	0.02	0.024	0.001	0.005	0.127	0.005	0.009	0.003	0.011	9.715
SW3	2695138	337732	7.91	29.6	7760	4966	1858.17	152.33	148.594	28.843	1597.5	2054.4	49.6	9.2	0	0	0.01	0.014	0.002	0.003	0.172	0.017	0.009	0.003	0.019	8.932
SW4	2700392	337347	7.85	31.2	9510	5421	2565.78	256.898	154.263	44.613	1633	1699.2	43	61.7	0.5	0	0.01	0.014	0.002	0.004	0.180	0.017	0.003	0.003	0.011	9.826
SW5	2704353	332843	7.71	31.4	13660	5754	3330.01	234.05	325.542	52.025	4047	1968	31	32.1	0	0	0.02	0.018	0.001	0.005	0.289	0.003	0.009	0.003	0.011	11.469
SW6	2706211	331577	7.7	30.6	10720	6086	2530.83	418.237	282.179	46.345	1952.5	2841.6	30	8.9	0	0	0.01	0.018	0.001	0.005	0.159	0.072	0.001	0.004	0.016	16.584
SW7	2706952	332417	6.08	29.8	13660	6163	3111.75	541.079	344.091	62.796	3479	3264	0	214.5	0	23	0.032	0.013	0.001	0.005	0.098	0.005	0.004	0.011	0.011	13.761
SW8	2707624	333972	7.5	30.7	13590	6861	3329.38	444.794	307.96	35.513	3053	3264	19	62.3	0	0	0.01	0.013	0.003	0.005	0.087	0.017	0.003	0.015	0.011	11.312
SW9	2708176	334462	7.43	29.7	12870	7251	2858.4	668.714	316.738	55.883	2875.5	3350.4	16.4	310	0	28	0.024	0.014	0.001	0.007	0.106	0.017	0.009	0.008	0.046	22.478
SW10	2708271	335943	7.53	29.3	11330	7629	2663.73	425.963	233.573	41.694	2662.5	2726.4	20.7	46.3	0	0.9	0.031	0.025	0.001	0.003	0.126	0.015	0.001	0.030	0.011	24.812
SW11	2708806	336667	7.41	31.9	19080	8179	4221.95	358.084	680.62	67.904	5893	3859.2	15.6	25.3	3.5	0.946	0.01	0.025	0.001	0.008	0.308	0.005	0.009	0.003	0.011	26.067
SW12	2708938	338578	7.94	31.4	7580	8237	1841.57	160.471	118.729	27.589	1952.5	1075.2	53	72.5	0	0	0.018	0.062	0.001	0.014	0.140	0.017	0.002	0.016	0.024	24.989
SW13	2709916	339414	8.1	32.5	4590	8698	1243.67	44.5542	45.2909	14.796	1065	720	76.8	6.8	0	0	0.01	0.020	0.001	0.005	0.242	0.017	0.001	0.003	0.011	4.610
SW14	2709218	328708	7.46	30.2	17070	8742	3441.23	863.428	599.271	74.090	4970	3091.2	17.5	26.7	0	0	0.057	0.026	0.001	0.005	0.245	0.092	0.003	0.003	0.067	33.708
SW15	2709524	325253	7.78	31.2	11920	8742	2772.94	209.154	332.438	58.395	3124	2764.8	36.7	57.5	0.6	0	0.037	0.023	0.001	0.011	0.304	0.235	0.008	0.003	0.011	23.152
SW16	2705817	330471	7.49	29.2	15230	9747	3501.12	807.44	370.609	67.959	3869.5	3974.4	18.8	88.2	0	0	0.037	0.032	0.001	0.015	0.175	0.009	0.002	0.003	0.011	35.469
SW17	2705454	329225	7.64	30.3	12780	10925	3004.97	402.121	303.836	51.784	3230.5	3648	26	11.3	2.1	0.7	0.049	0.027	0.001	0.014	0.247	0.042	0.004	0.003	0.011	27.443
SW18	2713861	324017	7.59	31.8	20000	11245	4732.87	265.38	715.224	74.050	6532	4032	23.7	23.6	0	0	0.039	0.025	0.001	0.005	0.408	0.052	0.002	0.003	0.011	27.549
SW19	2715528	321195	7.67	30.5	17570	12211	4102.58	510.759	539.56	74.871	5325	2553.6	28	18.1	0	0	0.028	0.022	0.001	0.016	0.407	0.749	0.009	0.013	0.011	26.686
SW20	2717363	317278	7.35	29.8	23700	12800	4986.04	829.198	966.588	109.687	7952	2937.6	13.6	5.8	0	0	0.023	0.031	0.001	0.011	0.233	0.017	0.009	0.032	0.077	36.498
SW21	2716527	317690	7.34	31.4	23200	14336	4845.57	571.26	1145.28	84.440	7881	3571.2	13.3	11.2	2.5	0.7	0.029	0.033	0.001	0.016	0.359	0.042	0.009	0.003	0.053	46.587
SW22	2716856	318426	7.37	30.5	23100	14784	4717.89	819.555	1024.58	89.498	7952	2976	14.2	58.6	0	0	0.01	0.031	0.001	0.005	0.286	0.019	0.001	0.003	0.062	41.984
SW23	2715210	319558	7.38	30.8	22400	14848	4856.33	595.944	810.448	86.092	7703.5	1420.8	14.6	26.7	0	0.3	0.023	0.030	0.001	0.007	0.365	0.007	0.009	0.003	0.011	35.762
SW24	2714643	320564	7.42	30.9	25600	14848	5642.39	926.031	1005.99	101.833	8626.5	4368	16	100.8	0	21	0.064	0.040	0.001	0.022	0.214	0.025	0.001	0.003	0.065	40.148
SW25	2713857	321934	7.39	31.7	23200	15168	5151.5	427.137	1012.45	81.802	7810	3513.6	14.9	80	0	0	0.033	0.024	0.001	0.009	0.359	0.020	0.000	0.003	0.011	36.882
SW26	2712988	322486	7.8	32.4	24000	15360	5064.61	304.382	1137.75	78.081	8591	2179.2	38.5	42.4	0	28	0.023	0.028	0.001	0.005	0.488	0.028	0.002	0.003	0.041	39.314
SW27	2703253	318559	7.9	31.8	9630	16384	2465.39	190.427	125.556	36.278	2343	2380.8	48	33.9	2.2	0	0.01	0.030	0.001	0.005	0.343	0.017	0.009	0.003	0.065	22.171

4.3. Major Cations

The major sequence of cations dominance in groundwater of the quaternary sandstone aquifers at Sweihan region has the order of $Na^{+} > Mg^{+2} > Ca^{+2} > K^{+}$ (see Table 3). Below is detailed discussion of each chemical parameter.

analysis values in (mg/l)	Major cations				Major anions			
	Na^{+}	K^{+}	Mg^{+2}	Ca^{+2}	Cl^{-}	SO_4^{-2}	HCO_3^{-}	NO_3^{-}
Minimum	1243.7	14.8	45.3	44.5	1065	720	13.3	5.8
Maximum	5642.4	109.7	1145.3	926	8626	4368	76.8	310
Mean	3446.4	59.5	491.9	435.1	4446	2794.7	76.8	54.2
WHO permissible limits 2011	200	-	50	-	250	500	500	50

Table 3: Mini/Maxi, Mean values, WHO permissible limits of major cations & anions in GW samples

4.3.1. Sodium (Na^{+})

Sodium is a highly soluble chemical and it is abundant in the earth. Most rocks and soils have sodium compounds, so all groundwater contains some sodium. Sodium can be tasted at concentrations of 200 mg/l or more as stated in WHO guidelines for drinking water (WHO, 2011). When exceeding the limit, it gives salty taste together with the presence of chloride.

High amounts of sodium in groundwater could indicate pollution from point or non-point sources or salt-water intrusion. Heavy consumption of sodium can be a risk factor for many diseases (WHO Guidelines, 2006). Natural sources of sodium include dissolution of clay minerals feldspars, brackish water, and seawater intrusion in the coastal areas. Anthropogenic sources include sewage, agricultural and industrial effluents and soil leachate that is high in sodium (Panno, 2006).

High amounts of sodium in arid and semi-arid basins might occur because of evaporate dissolution and evaporation influences (Richter et al., 1993; Edmunds et al, 2003). In the study area, the Na^+ values of groundwater samples were in the range of 1244 to 5642 mg/l. All samples exceeded the standard limit of the WHO, which indicates that the groundwater cannot be used for drinking as shown in (Figure 17).

As groundwater has high TDS and EC, salt solution concentration (NaCl) is very common high sodium values in Sweihan area to indicate a significant source of agricultural leachate and effluents into groundwater. The use of fertilizers and irrigation causes increase in sodium amounts in the groundwater. In addition, poor soil texture causes infiltration of sodium easily into groundwater. Moreover, Sweihan area is rich of sedimentary ores, such as carbonate, silicate and sulphate compounds that sodium is commonly attached to forming many forms of salts (Panno, 2006).

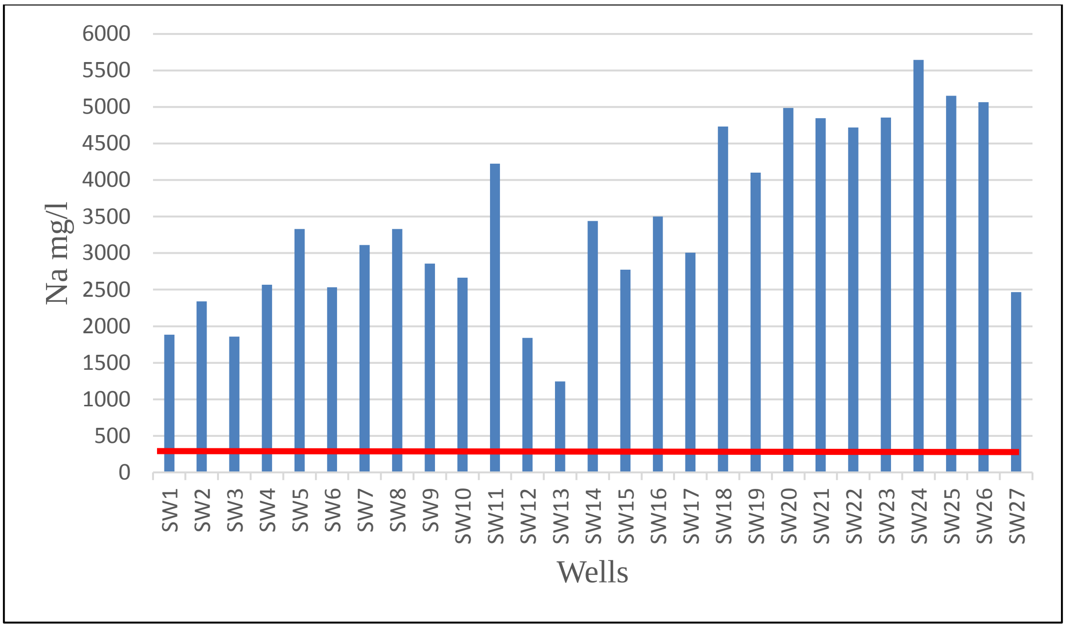

Figure 17: Na^+ values of Sweihan GW samples compared with WHO 2011 permisssible limits

Referring to (Figure 18), the highest values are concentrated in the northwest towards the east. In previous studies of Food Inspection Centre in Al-Ain, results showed very high sodium values ranging from 513-4519 mg/l (ADFCA, 2005).

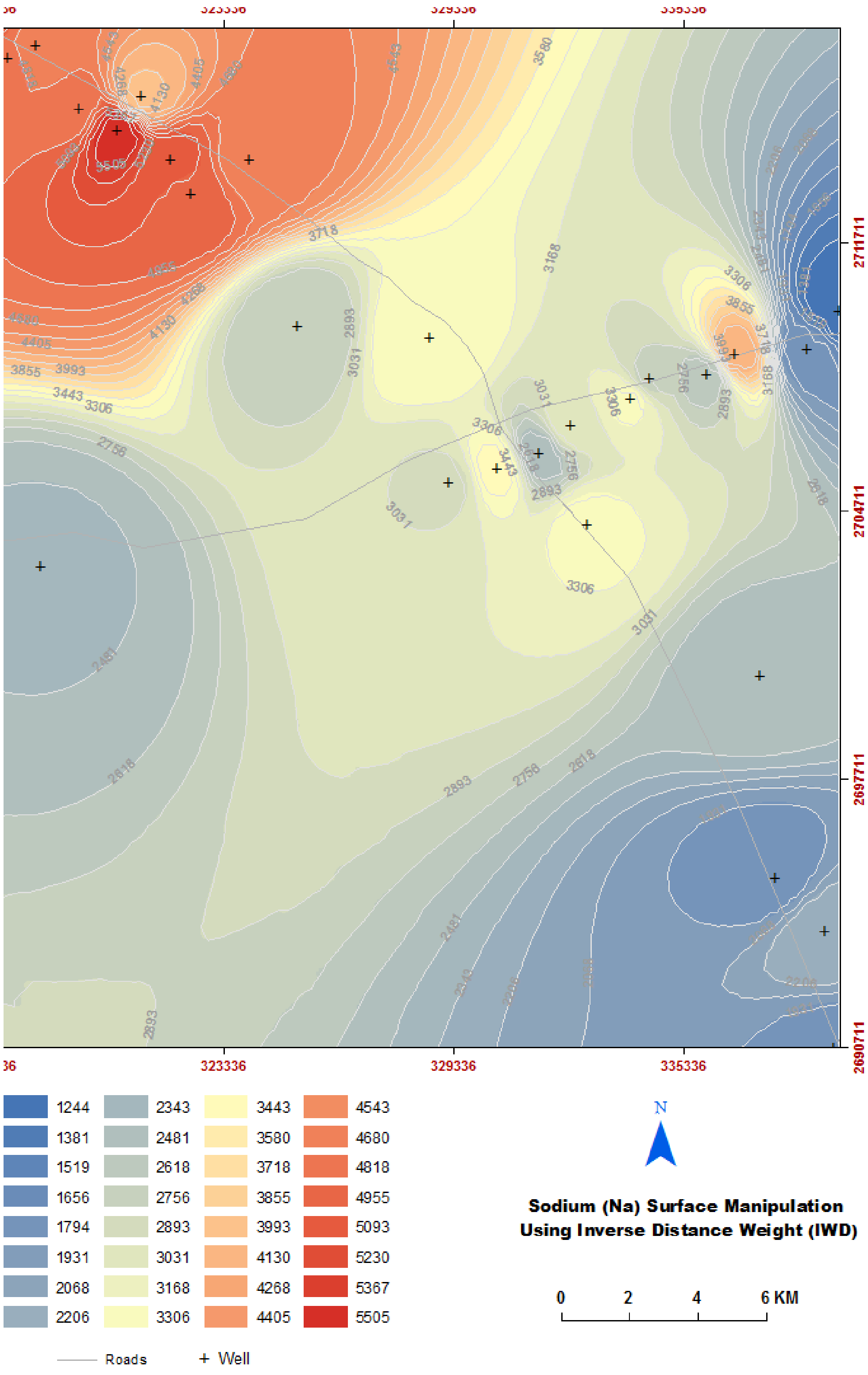

Figure 18: Contour map of Na^+ distribution of GW samples in the study area

According to (Figure 19), the ratio of 0.94 shows a very strong relationship between sodium and chloride suggesting that both sodium and chloride is present from the same source. The first source is the heavy agricultural activities and their effluents in the area. The other source could be the high saline water in the area that could evaporate and leave the salt behind. Erosion of rock minerals containing salt compounds as mentioned previously is another reason (El-Mahmoudi, 2008).

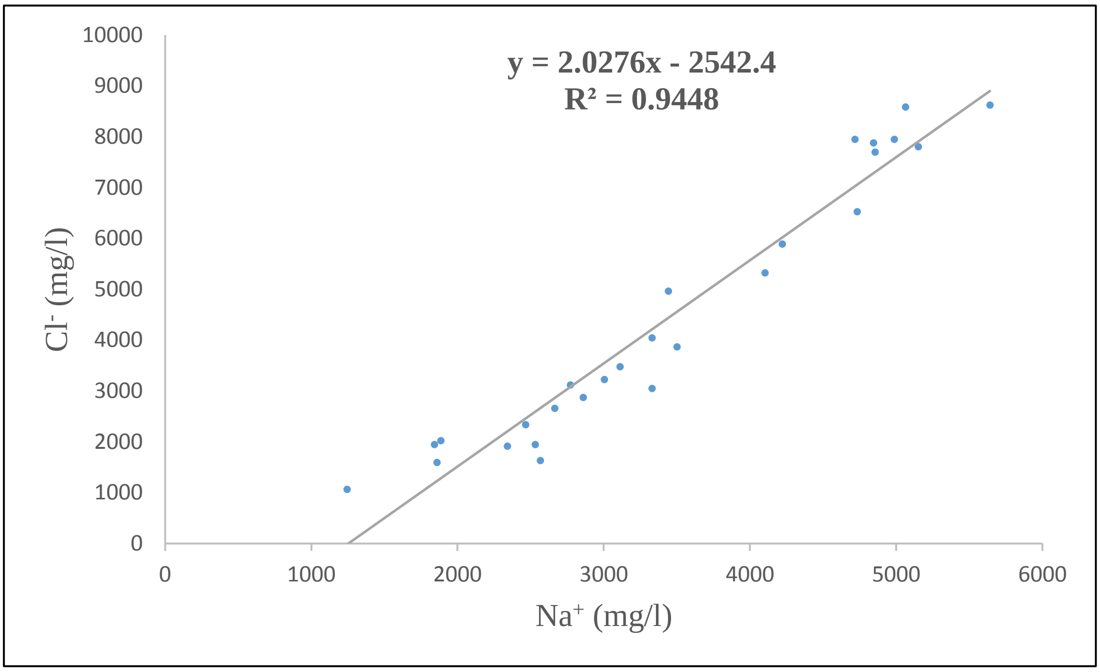

Figure 19: The relationship between Na^+ and Cl^- of GW samples

4.3.2. Potassium (K^+)

K^+ is a very common element found in water and increases during time due to dissolution of rocks. The main sources of potassium are feldspars, feldspathoids, mica and clays. Generally, it has low concentration of <10 mg/l in natural fresh water. Potassium is strongly attached by clay particles on soil and considered one of the important fertilizers (Todd, 1980).

The K^+ values in Sweihan groundwater samples range between 14.8–109.69 mg/l. The high values concentrate in the northwest as expressed in (Figure 20). K^+ has no standard level for drinking water in the WHO 2011guidelines, as it appears in water with amounts that does not have threats to human beings.

The presence of K^+ in the study area could be due to silicate minerals such as gypsum, feldspars and clay, which are present in the area. Increasing K^+ existence in groundwater is a result of agricultural runoff, where K^+ is the main constituent in the fertilizers that added to crops (Juned, 2011). K^+ has a very strong relationship with TDS (R=0.9), which indicates that K^+ is one of the major contributing element of TDS increase in groundwater expressed in (Figure 21) (Allison, 1954).

Furthermore, K^+ has a strong relationship with Na^+ as shown in (Figure 22). The ratio (R^2=0.9) means that both Na^+ and K^+ originate from same source. This source should be the agricultural effluents and runoff that leach through soil into groundwater (Chapman, 1996). In addition, sodium and potassium are commonly added in fertilizers' compounds, as they are important nutrients for plants (US EPA, 1991).

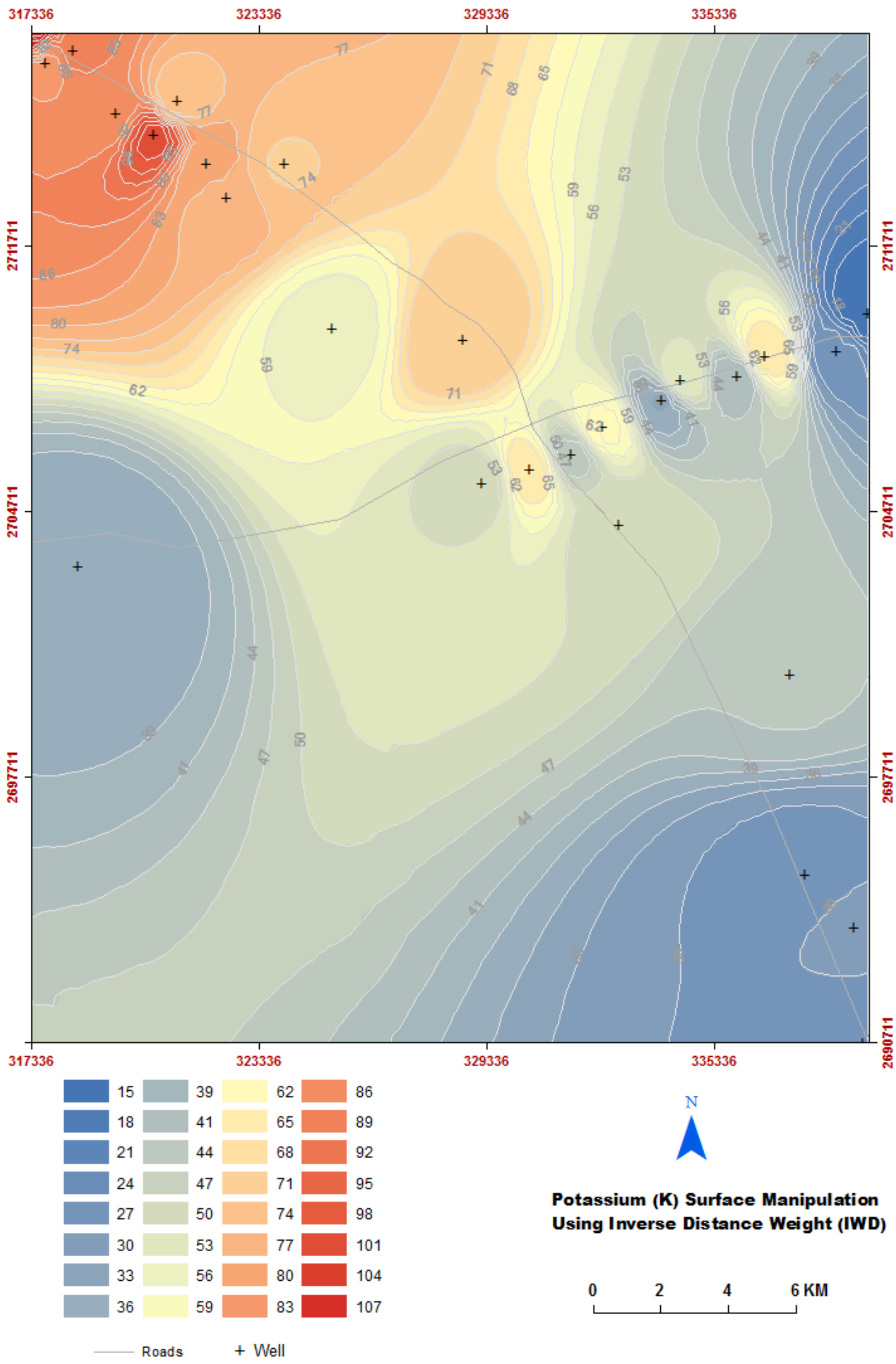

Figure 20: Contour map of K^+ distribution of GW samples in the study area

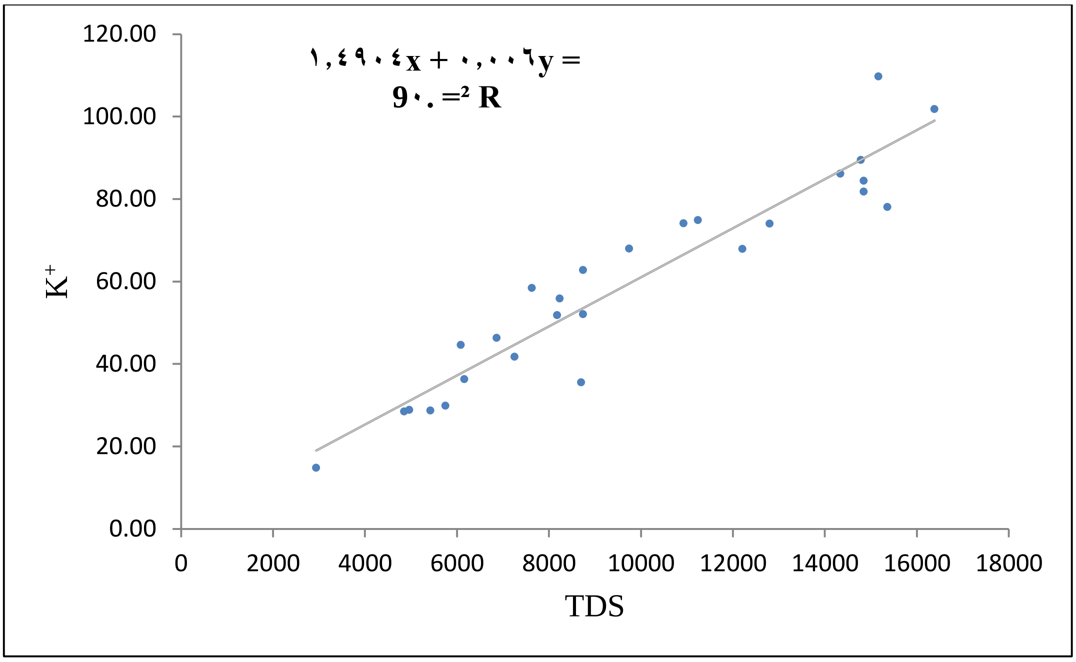

Figure 21: K^+ and TDS relationship of GW samples in the study area

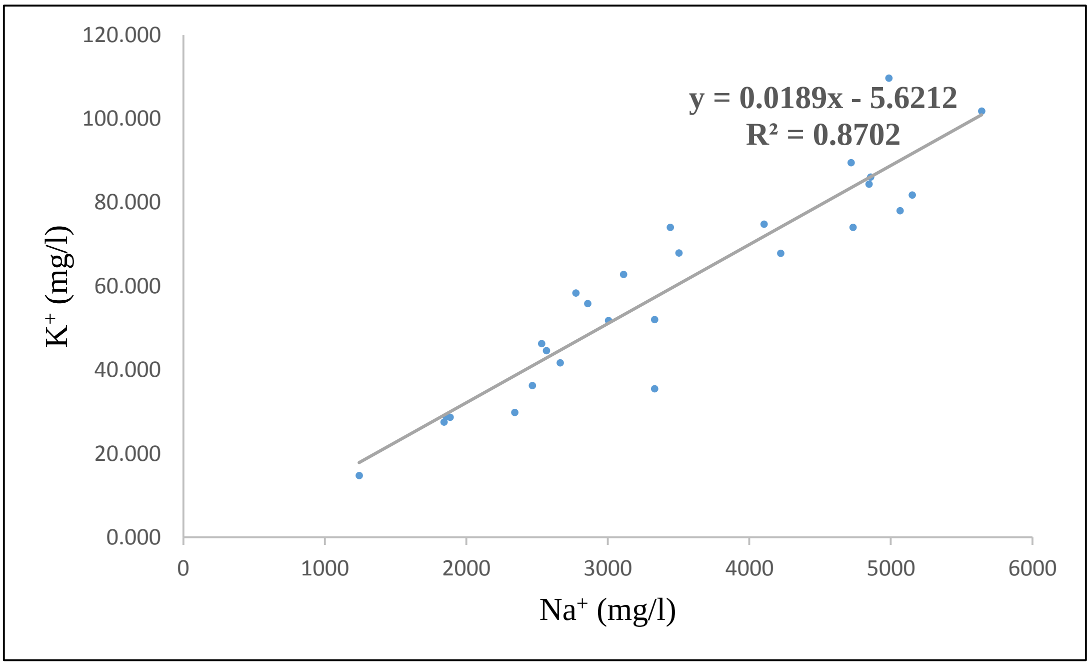

Figure 22: The relationship between K^+ and Na^+ of GW samples in the study area

4.3.3. Magnesium (Mg^{+2})

Magnesium is a major constituent found in water. It is found in amphiboles, gypsum, pyroxenes, dolomite, magnesite, clay minerals, and weathered minerals from ophiolite rocks (Department of Natural Resources, 2002). Magnesium concentration in fresh water is less than calcium because of the low geochemical abundance of magnesium.

Concentration of magnesium in the study samples ranges from 103.074 – 1145.28 mg/l, with the exception of one sample (No.13) of value 45.29 mg/l. Magnesium values are all exceeded 50 mg/l which is the permissible limits of WHO for drinking water. Magnesium concentration is according to (Figure 23), increases in the northwest and decreases toward the east. The reason of the abundance of Mg^{2+} in groundwater is the weathering of dolomite $(CaMgCO_3)_2$ (El-Mahmoudi, 2008). (Figure 24) expresses the relationship of TDS and magnesium. As magnesium is one of TDS main contributors, the relationship ratio between magnesium and TDS is high (R^2=0.9).

Magnesium and sodium together as ionic salts have good relationship (R^2=0.9), shown in (Figure 25). This value indicates that both elements increase in the groundwater from the common source, which largely is an agricultural activity. Magnesium increases in the groundwater because farmers use the same groundwater pumped from wells, which contain magnesium and other elements in irrigating the farms, so it increase the accumulation of magnesium in the groundwater. Magnesium as well is present in some fertilizers that are used for different yields (Allison, 1954).

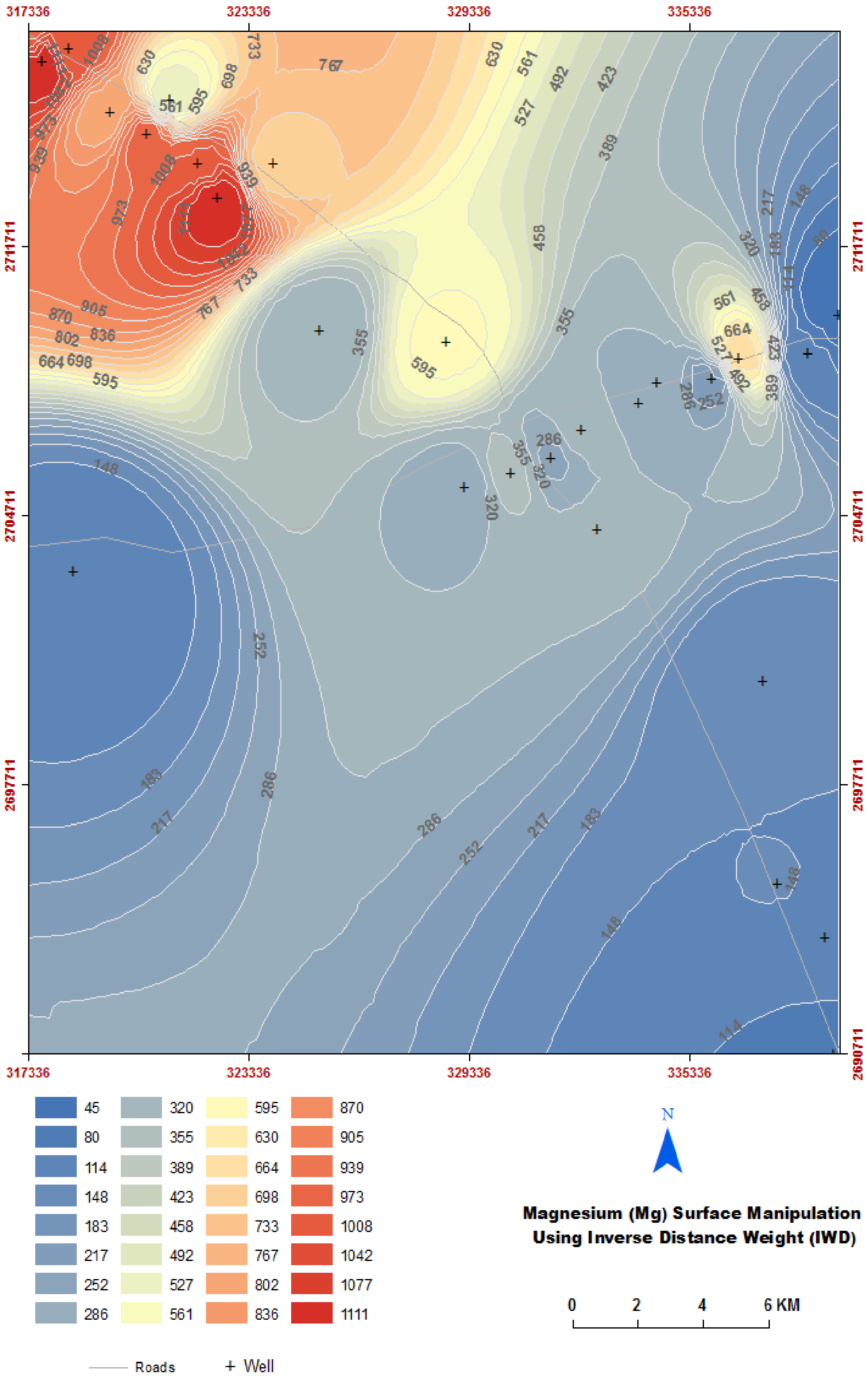

Figure 23: Contour map of Mg^{+2} distribution of GW samples in the study area

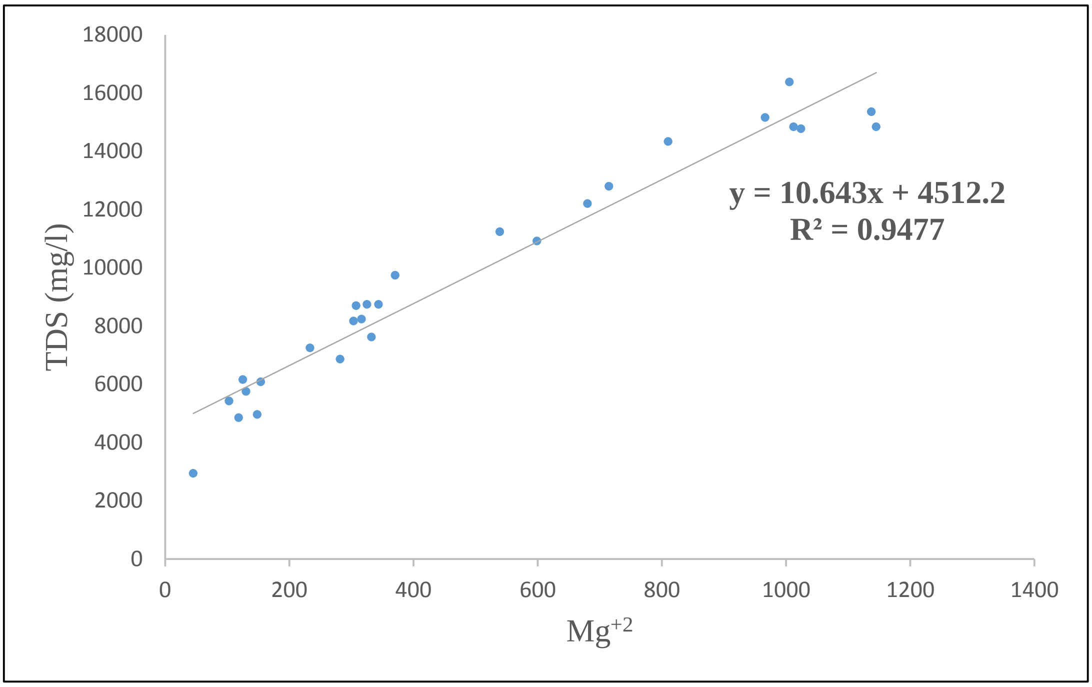

Figure 24: The relationship between TDS and Mg2+ of GW samples in the study area

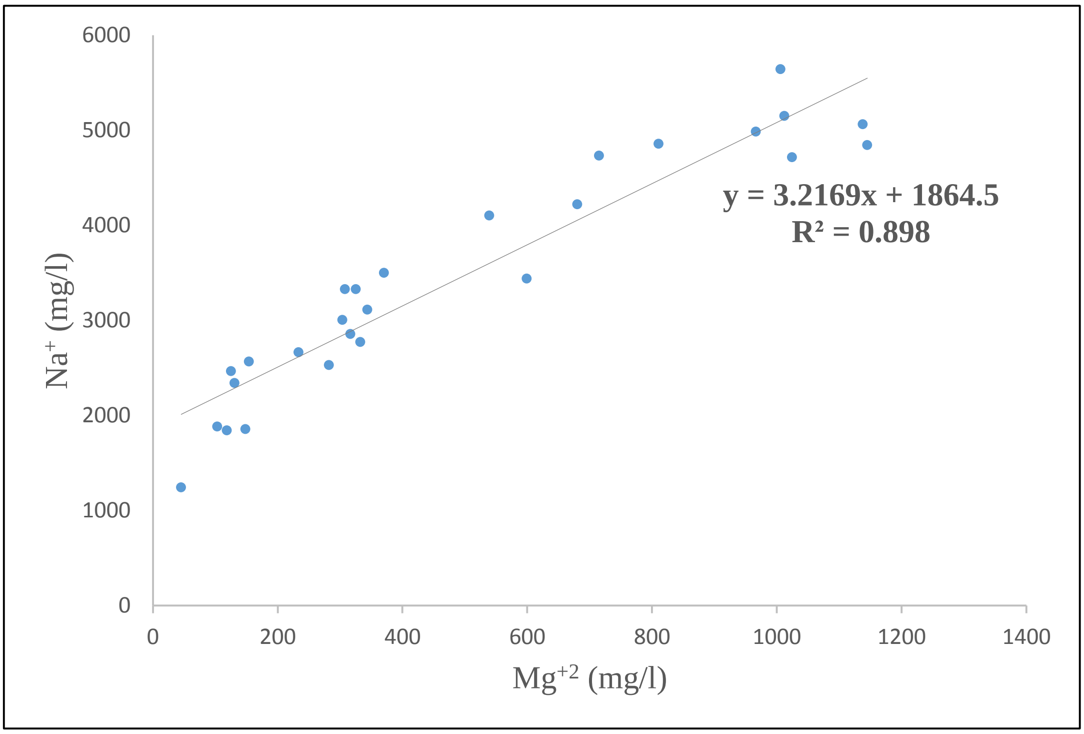

Figure 25: The relationship between Na+ and Mg2+ of GW samples in the study area

4.3.4. Calcium (Ca^{+2})

Calcium is derived from dissolution of anhydrite ($CaSO_4$), gypsum ($CaSO_4 \cdot 2H_2O$) and limestone ($CaCO_3$) giving dolomite [$CaMg(CO_3)_2$] and calcite ($CaCO_3$). Calcium together with magnesium are both common in rocks and water (Obiefuna, 2011). Calcium ranges in the study area from 44.55 to 926 mg/l. Calcium has two trends in the region. It is concentrated in the northeast of the study area and in the middle (Figure 26).

WHO guidelines, 2011 did not specify a permissible limit for calcium in drinking water, but stated that calcium permissible limit in groundwater should be 75 mg/l. according to the WHO (2011) guidelines; groundwater samples in the study area are considered not acceptable for drinking purposes. High concentrations of calcium in Sweihan area originate from dissolution of sedimentary minerals as gypsum ($CaSO_4 \cdot 2H_2O$) and anhydrite ($CaSO_4$) and limestone ($CaCO_3$) which are abundant in the study area (El-Mahmoudi, 2008).

Magnesium and sodium together as ionic salts have good relationship (R^2=0.9), shown in (Figure 27). This value indicates that both elements increase in the groundwater from the common source, which largely is an agricultural activity. Magnesium increases in the groundwater because farmers use the same groundwater pumped from wells, which contain magnesium and other elements in irrigating the farms, so it increase the accumulation of magnesium in the groundwater. Magnesium as well is present in some fertilizers that are used for different yields (Allison, 1954).

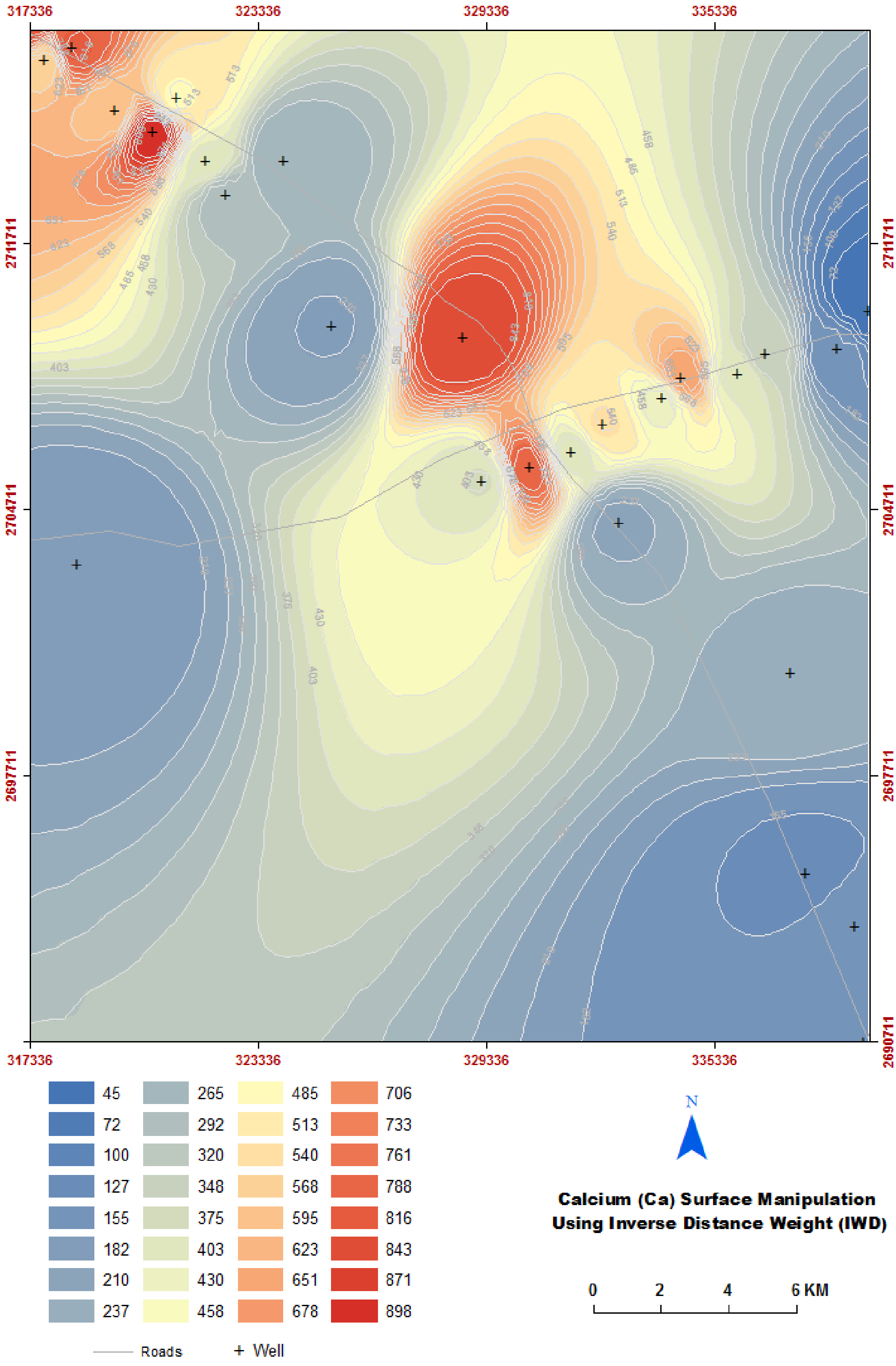

Figure 26: Contour map of Ca^{+2} distribution of GW samples in the study area

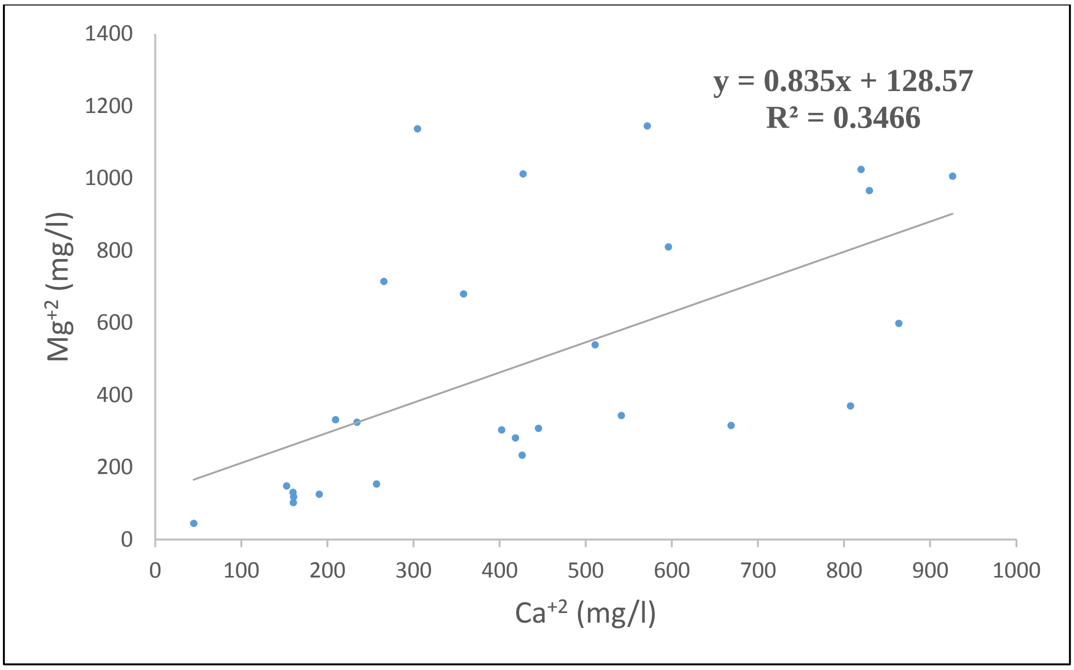

Figure 27: Relationship between Ca^{2+} and Mg^{2+} of GW samples in the study area

4.4. Major Anions

The major anions that found to be dominant in the groundwater samples from the study were Cl^-, SO_4^{-2}, HCO_3^-, and NO_3^-.

4.4.1. Chloride (Cl^-)

Chloride is a widely spread element in nature, and considered a major constituent in groundwater in semi-arid regions. Dissolution of feldspathoid, sodalite and phosphate mineral apatite and sedimentary rocks such as evaporites causes chloride presence in groundwater (Hem, 1985). Chloride usually forms different compositions of salts such as sodium chloride ($NaCl^-$), potassium chloride (KCl^-) and calcium chloride ($CaCl_2^-$).

Anthropogenic sources that cause increase in chloride occurrences in groundwater are agricultural practices, sewage, industrial wastewater (Ravi Prakash, 1989). According to the WHO guidelines, chloride level above 250 mg/l in drinking water can be detectable and causes salty taste (WHO, 2011). High concentration of chloride in groundwater results in high salinity. Heavy extraction of groundwater in an area with low rainfall levels could lead to high salinity (Murad, 2011). Chloride with small amounts has no or little effect on suitability of water. If it exceeds 600 mg/l it markedly impair the potability of water. Chloride can be detected in water easily by the salty taste of water. Chloride increases the rate of corrosion in water pipes (Jamshidzadeh, 2011).

In Sweihan groundwater samples, Cl^- concentration ranges from 1065 to 8627 mg/l. The trend of concentration increases from east to northwest as of sodium trend (Figure 28). Concentration of Cl^- in the area is considered very high comparing with WHO standards (250 mg/l). As discussed earlier in (Figure 19), Cl^- and Na^+ are related (R^2=0.9), which indicates agricultural activities. Moreover, strong relationship (R^2=0.85) is shown in (Figure 29), between K^+ and Cl^- indicates that agricultural activities in the area is one of the main sources of chloride presence (Ravi Prakash, 1989).

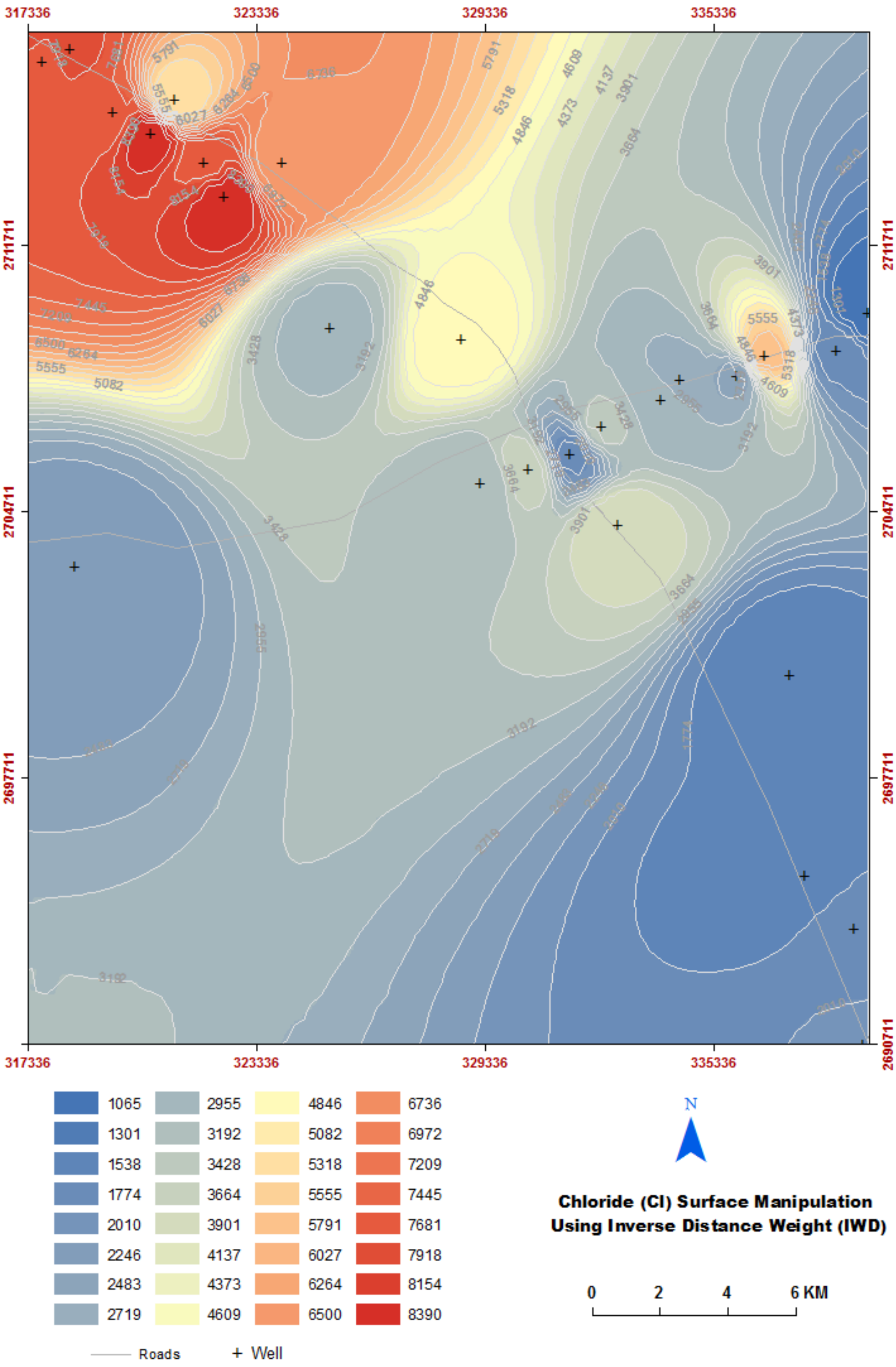

Figure 28: Contour map of Cl^- distribution of GW samples in the study area

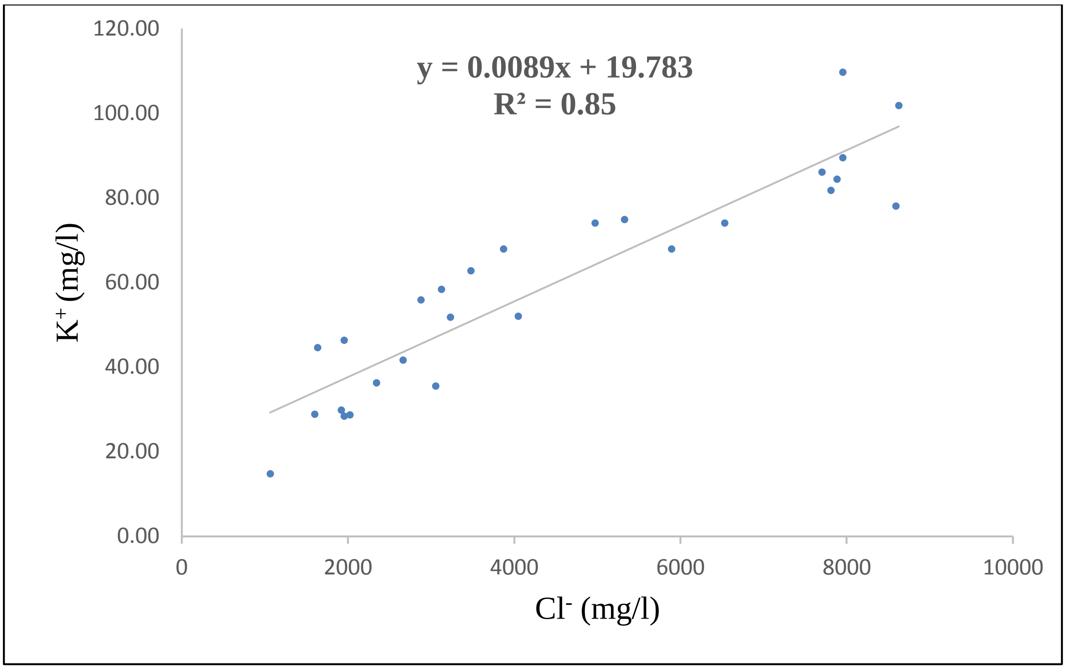

Figure 29: Relationship between Cl^- and K^+ of GW samples in the study area

4.4.2. Sulphate (SO_4^{-2})

Sulphate is derived from gypsum ($CaSO_4 \cdot 2H_2O$) and oxidation of sulphide minerals (Egbunike, 2007). More than 250 mg/l in water causes bitter taste, laxative effects for some people, and corrosion of water pipes and distributing systems. It is recommended by health authorities that sulphate does not exceed 500 mg/l (WHO, 2011).

Commonly, sulphate is associated with high concentration of chloride, sodium, calcium and bicarbonate, and presents in saline water (Yidana, 2010). Sulphate concentration varies in the study area and ranges between 720 to 4368 mg/l. Sulphate has very high concentrations in the region comparing with WHO guidelines. Most samples are concentrated in the centre and northwest of the study area as shown in (Figure 30).

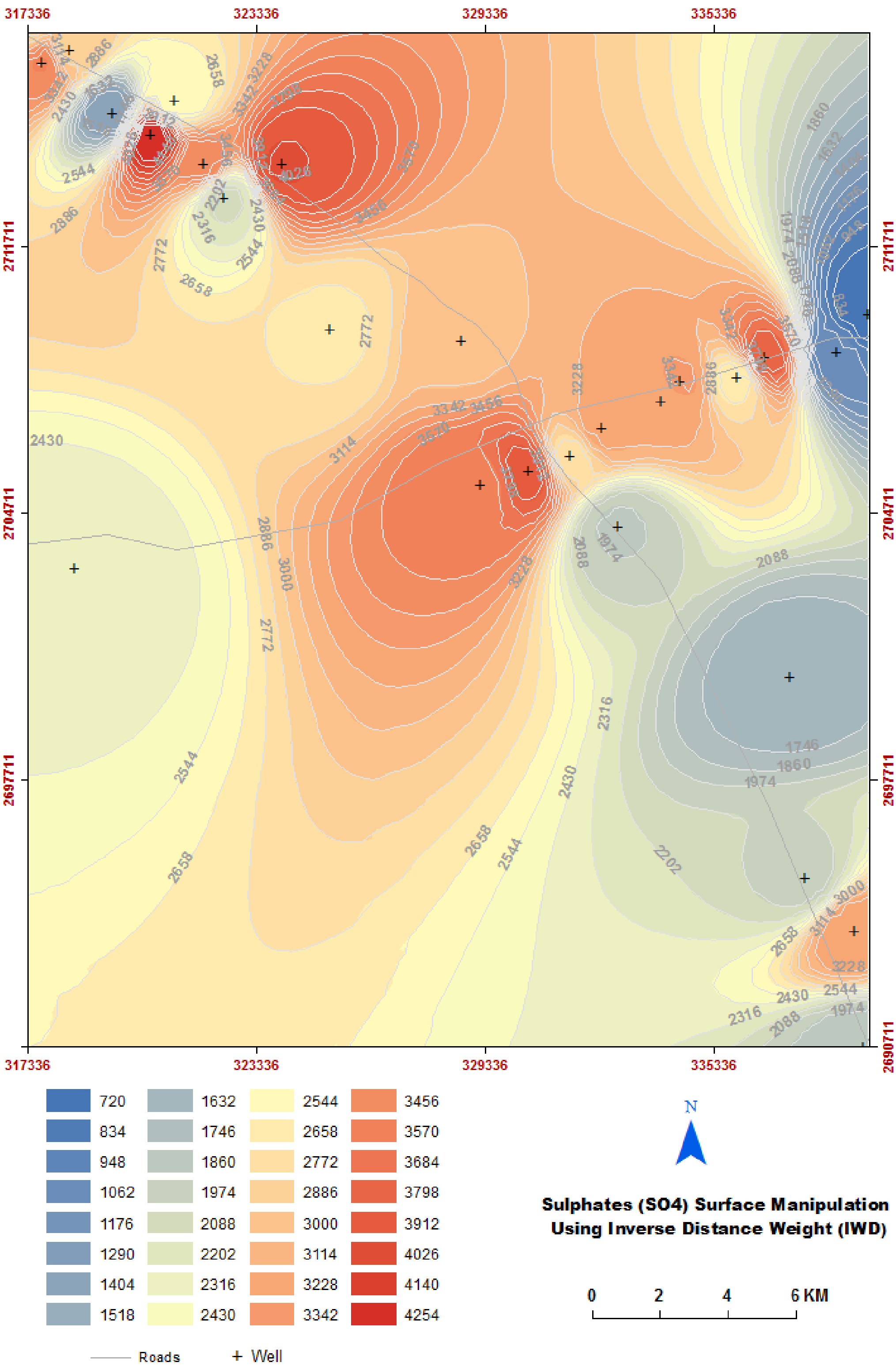

Figure 30: Contour map of SO_4^{-2} distribution of GW samples in the study

Most related source of its high presence is gypsum and anhydrite, which are found in the study area (Thomas, 2012). It concentrates in the centre and northeast of the study area. The poor relationship (R^2=0.2) between sulphate and TDS indicates that sulphate does not contribute to TDS concentration (Figure 31).

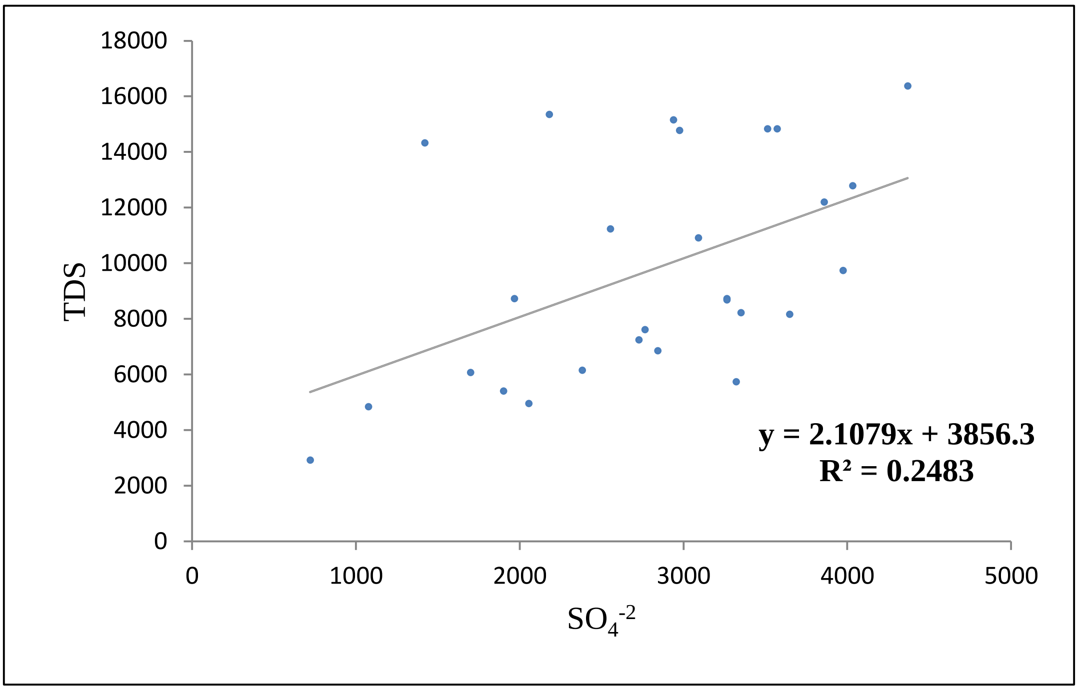

Figure 31: Relationship between SO_4^{-2} and TDS of GW samples in the study area

Therefore, sulphate and chloride has no relationship (R^2=0.16) suggesting that sulphate is not related to agricultural activities as for chloride and sulphate is coming from natural resources (Figure 32). Therefore, SO_4^{-2} concentrations in Sweihan region are from dissolution of gypsum and anhydrite present in the area (Mohsen, 2013).

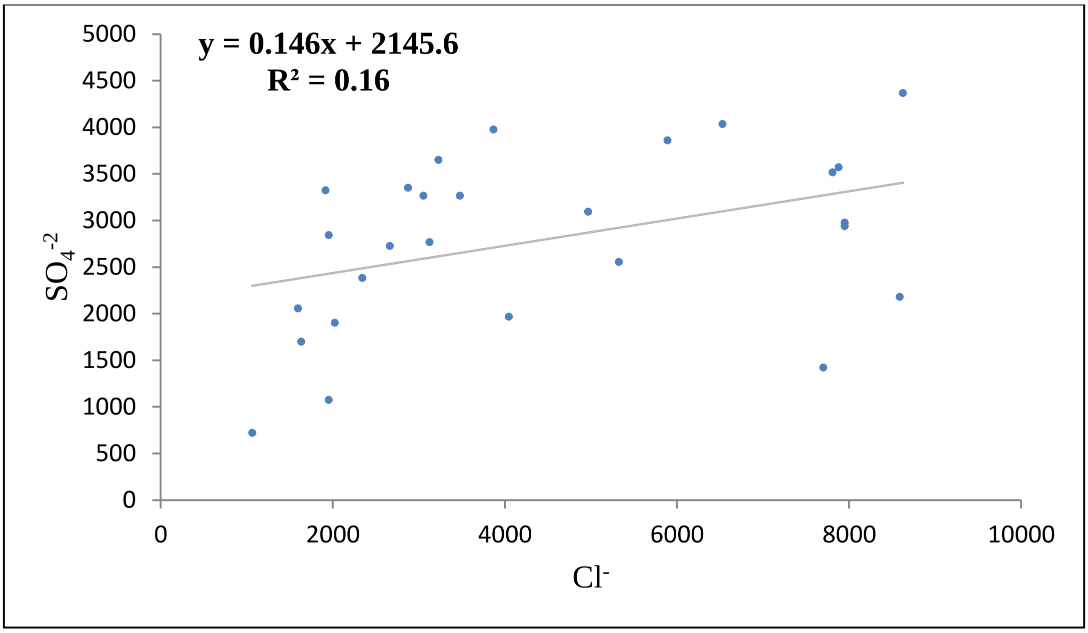

Figure 32: Relationship between SO_4^{-2} andCl^- of GW samples in the study area

4.4.3. Bicarbonate (HCO_3^-)

HCO_3^- is easily dissolve in water and usually originates from weathering of feldspars and ferro-magnesium minerals by carbonic acid (Monjerezi et al., 2012). As well, it comes from dissolution of carbonate rocks and water-rock interaction (Murad et al., 2011). Although, there are no exact permissible limits for bicarbonate in WHO guidelines (2011), the presence of HCO_3^- in drinking water should not exceed 500 mg/l in order to be safe for human consumption. HCO_3^- has a critical contribution to alkalinity of groundwater (Mohsin et al., 2013).

Alkalinity is defined as the ability of water to neutralize an acid and expressed in the form of $CaCO_3$. As HCO_3^- is derived from $CaCO_3$ and $MgCO_3$, alkalinity and total hardness are connected, and relatively have similar ranges (TSC, 2009). Sweihan area has reasonable concentration amounts of bicarbonate ranging between 14-76.8 mg/l. The presence of HCO_3^- in Sweihan region is due to limestone weathering and feldspars. HCO_3^- increases from west and SW towards the NE (Figure 33).

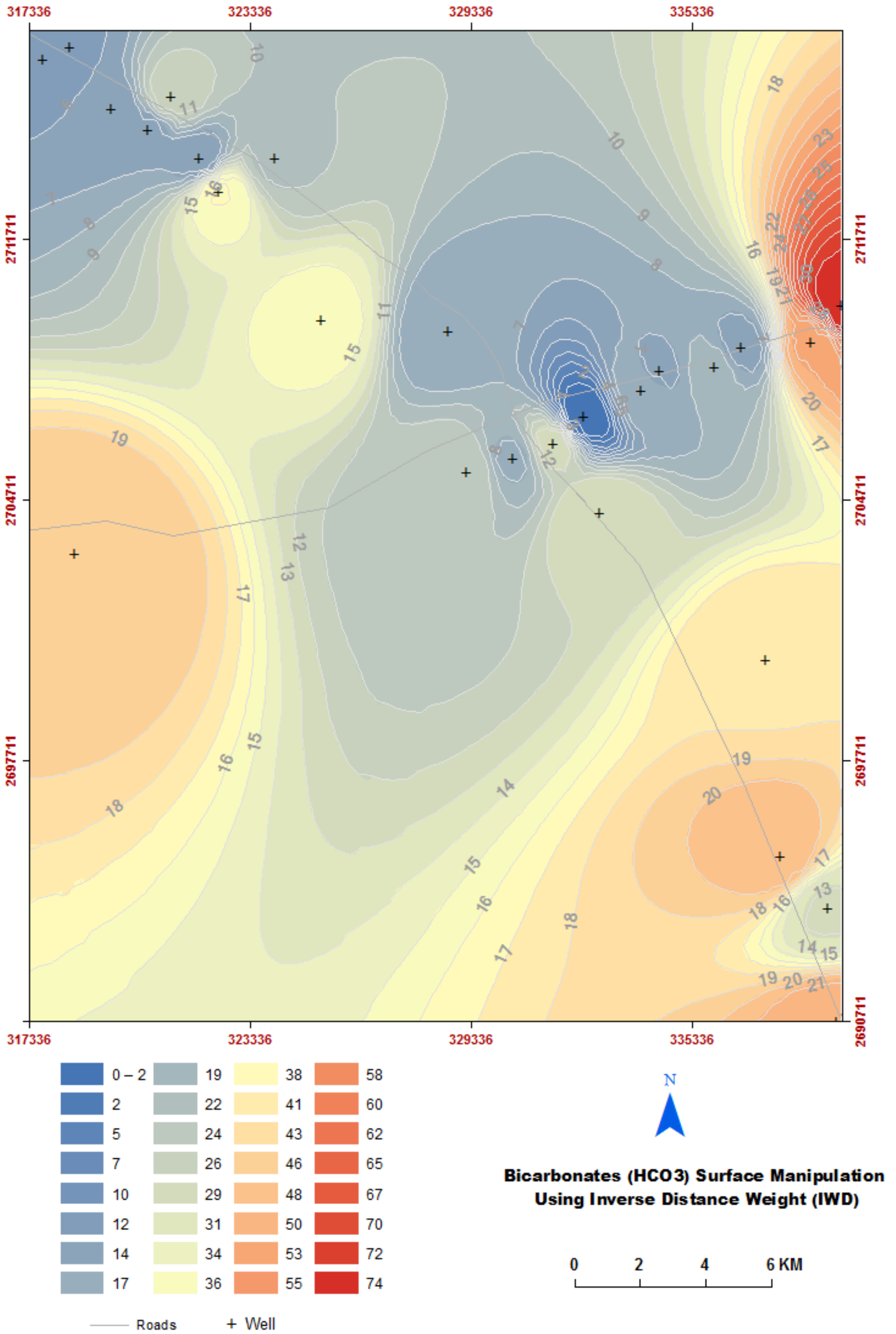

Figure 33: Contour map of HCO_3^- distribution of GW samples in the study area

4.4.4. Nitrate (NO_3^-)

NO_3^- ions present in water due to use of fertilizers, biocides during irrigation (Zhang, 2007). The excessive use of nitrogenous fertilizers, and the presence of sewage in the area, could lead to NO_3^- leakage into groundwater (Weil, 1990). Nitrate has health effect as it could cause blue-baby syndrome for infants after high exposure (WHO, 2011). The range of NO_3^- concentration in the study area is from 5.8 to 310 mg/l; out 27 samples, 11 samples exceeded the NO_3^- permissible limit of 50 mg/l regarding the WHO 2011 guidelines. NO_3^- increases from south to north as shown in (Figure 34).

Murad et al (2011) suggested that if the ratio between K^+ and NO_3^- is high, then the agriculture is one of the main sources for both and agriculture is contributing to water quality in the region as shown in (Figure 35). Therefore, expressing a negative relationship (R^2=0.0056), which concludes that there are other anthropogenic contamination sources that contribute to NO_3^- concentration other than agricultural activities in the area (Choi, 2011). NO_3^- could initiates from domestic wastewater effluents in the form of ammonium (NH_4^+), or from natural soil NO_3^- in the form of nitrite NO_2^- (Boumer, 1978).

NO_3^- was measured in Sweihan in 2013 as 10 microgram/cubic meter (EAD, 2014). Therefore, nitrite could be one of the sources of nitrate presence in the study area. Other suggested sources are animal manure and septic system. The study area contains different types of human activities such as camel farms, poultry farm and other feedlots. Animal waste could be one of the major NO_3^- sources in the area. Septic tanks could be also present in small scales in the area, which lead to adding NO_3^- in the groundwater (American Farm Bureau Federation, 1987).

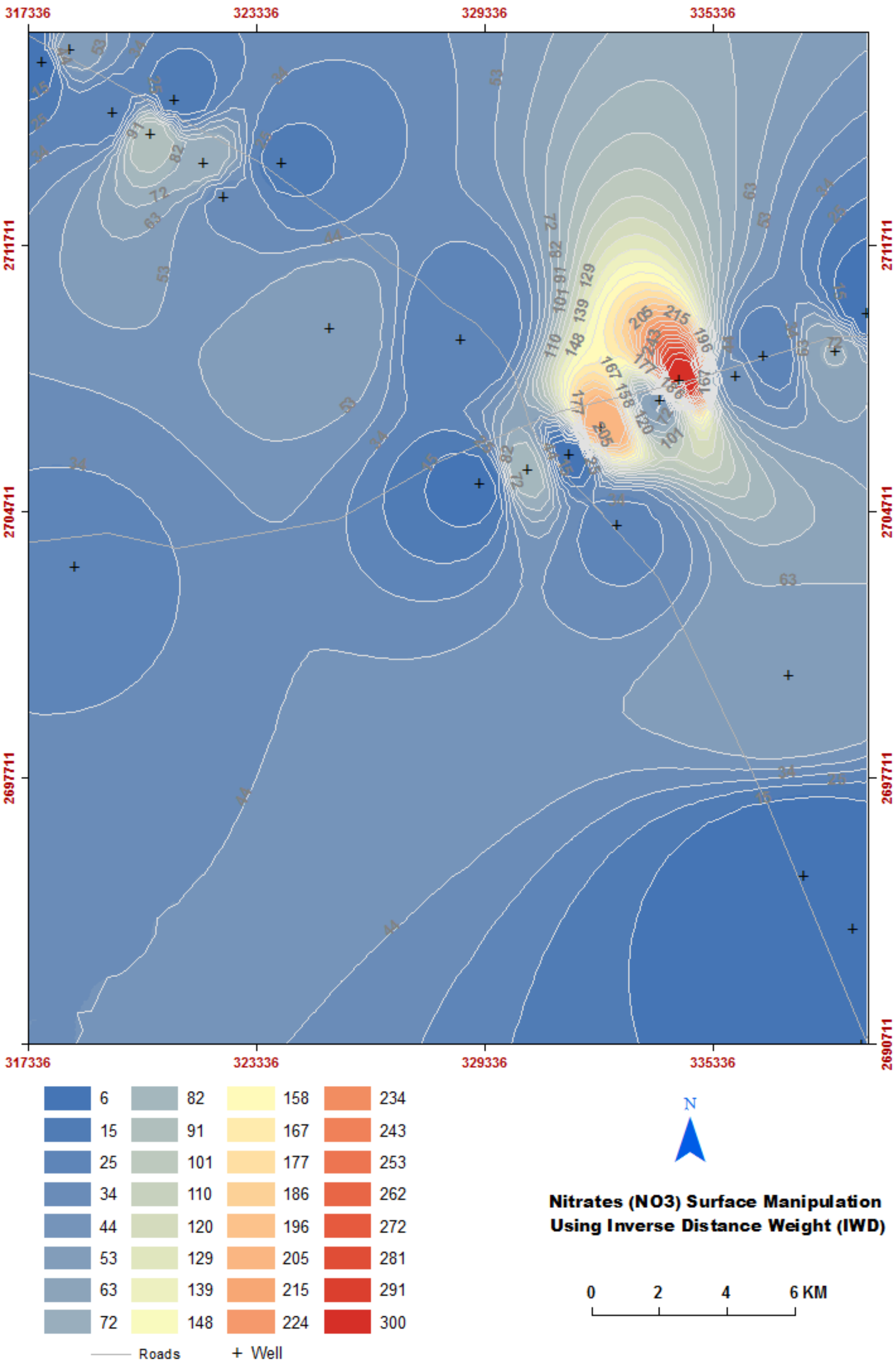

Figure 34: Contour map of NO_3^- distribution of GW samples in the study area

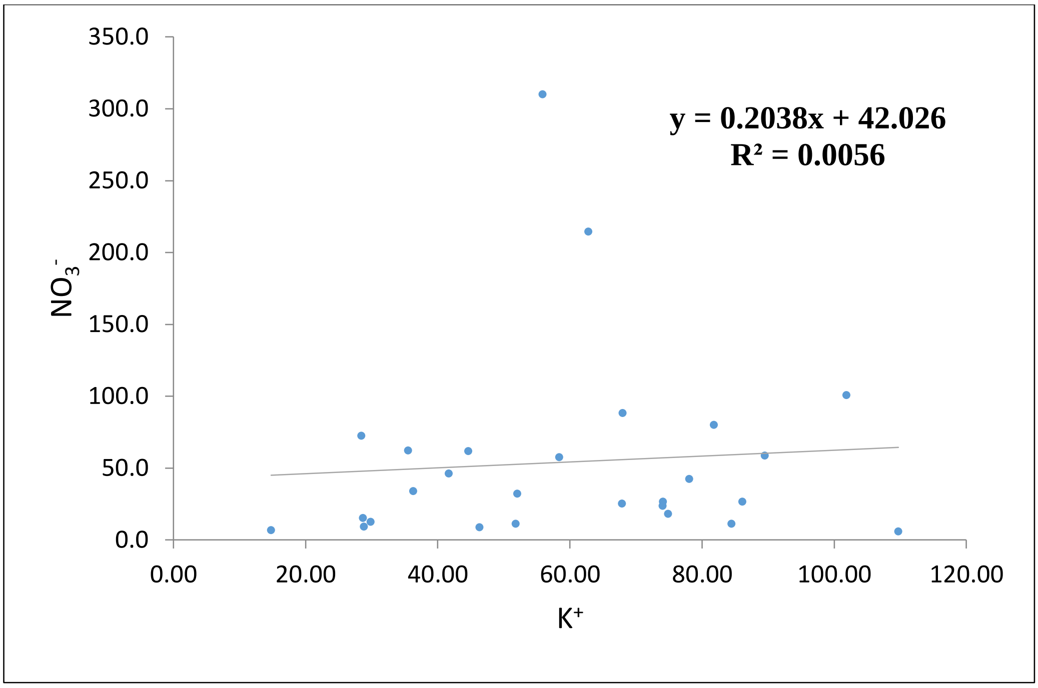

Figure 35: The relationship between NO_3^- and K^+ of GW samples in the study area

4.5. Trace Elements

The trace metals are one of the most common and environmentally concerned pollutants that severely destroy the aquatic system. The presence of trace metals could be from natural or anthropogenic causes. Once trace elements are released in the environment, they never disappeared nor destroyed, as they are non-biodegradable. They are whether dissolved to form ions or complexes, or suspended as particulate matter, or accumulated down as bed sediments (Zhang, 2009; Ali et al, 2013; Tuna et al, 2007).

Most of trace metals are mobile and have low soluble levels in water. High concentration of trace metals in the water, results in deterioration of water quality for drinking and irrigation. Moreover, trace metals are toxic to cause serious diseases to organisms leading to death if exposed to high concentrations (Niu et al, 2009). The trace metals in Sweihan area are chromium, lead, and strontium as shown in Table 4.

Trace elements	Minimum and Maximum value (mg/l)	WHO permissible limit (2011)	% of wells exceeding the limit
Aluminum (Al)	0.01-0.06	0.2	0%
Barium (Ba)	0.01-0.06	0.7	0%
Cadmium (Cd)	0.001-0.003	0.003	0%
Cobalt (Co)	0.002-0.02	0.4	0%
Chromium (Cr)	0.09-0.49	0.05	100% (27)
Iron (Fe)	0.003-0.7	No standard value	4 % (1)
Manganese (Mn)	0.00-0.009	0.1	0%
Strontium (Sr)	4.9-46.6	No standard value	---
Lead (Pb)	0.01-0.08	0.01	40% (11)
Nickel (Ni)	0.003-0.03	0.07	0%
Fluoride (F)	0.00-0.04	1.5	0%

Table 4: Significant trace metals in Sweihan area

4.5.1. Chromium (Cr)

Chromium is a widely distributed substance on earth's crust. It can be found from natural and anthropogenic source. Cr is naturally found in the form of Cr VI minerals. It is soluble and highly toxic. It is found in high alkalinity basins (pH=8-9) and saline basins (Godgul et al, 1995). It originates as well from the erosion of metamorphic rocks such as serpentinite (Henrie et al, 2002).

Natural chromium is considered more dangerous than manmade form as it presents in the oxidization environment. Moreover, Cr III is commonly found and is insoluble and less toxic. Sources of manufactured chromium are tanning, petroleum refining and other industrial applicants (Steinpress, 2004). Long-time exposure to chromium can lead to the possibility of having carcinogenicity effects. The WHO permissible limit for Cr in drinking water is 0.05 mg/l (WHO, 2011).

Sources of Cr in the study area are natural and synthetic source. The natural source of chromium in the study area is the presence of chromite ($FeCr_2O_4$) deposits in the ultramafic igneous rocks fragments found in the area. These fragments were derived originally from Oman Samail Ophiolite in the ancient ages (Hunting, 1979; Brown, 1980). Cr is also present in the serpentinite metamorphic rocks, which derived from dehydration of ultramafic rocks in the old time (Thomas, 2012).

On the other hand, Cr could derive from agriculture activities. Some chemical multi-nutrients fertilizers called NPK fertilizers contain certain amounts of Cr^{3+} on their production. The continuous use of these fertilizers will trigger the increase amount of Cr in the area (Battelle, 1999). Chemical analysis of groundwater samples in Sweihan revealed that all 27 samples are above the WHO permissible limit (0.09-0.49 mg/l). Chromium is concentrated in the northwest of the area, the same trend of salinity (Figure 36).

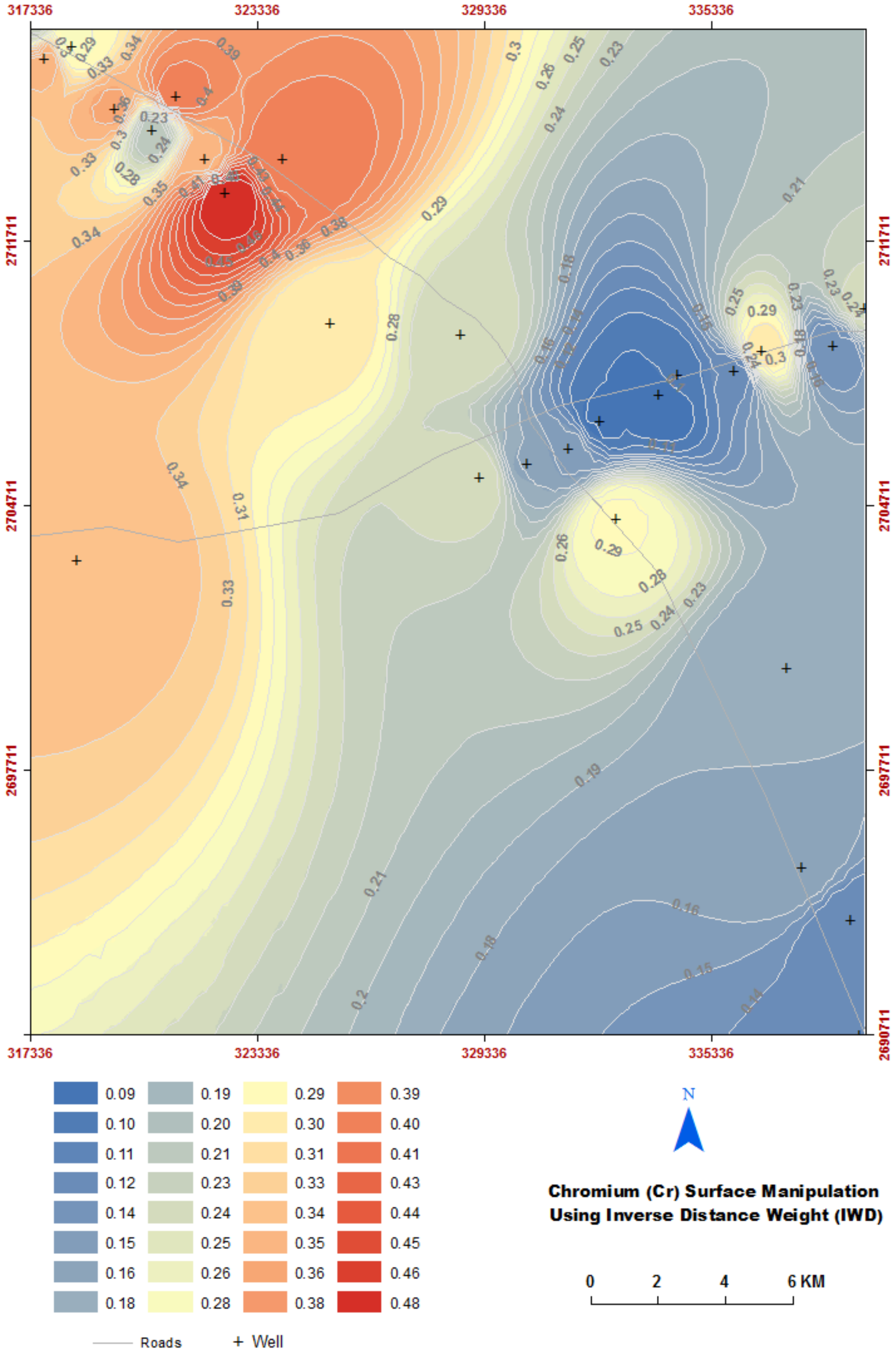

Figure 36: Contour map of Cr distribution of GW samples in the study area

4.5.2. Lead (Pb)

Pb mainly comes from municipal networks, water pipes, and plumbing in buildings. Pb is present in nature in very rarely in small amounts; it has the tendency to dissolve slowly in water, and quickly in hot acidic compounds. That is why; the concentration varies depending on pH, temperature and water hardness (Mohan & Hosetti, 1998).

Some of health effects that caused by Pb such as neurodevelopmental effects, mortality caused by cardiovascular diseases, impaired renal function, hypertension, impaired fertility and adverse pregnancy outcomes (EPA, 2009). As the permitted limit of Pb in drinking water according to WHO guidelines, 2011, is 0.01 mg/l, 11 samples out of 27 found to be exceeded the limit in the study area (Figure 37).

This high concentration could come from water pipes containing Pb or industrial waste and landfill near the area. Agricultural practices influence as well the presence of Pb as NPK fertilizers also contain amounts of Pb, which contribute to the increase amounts of lead in the study area (Battelle, 1999).

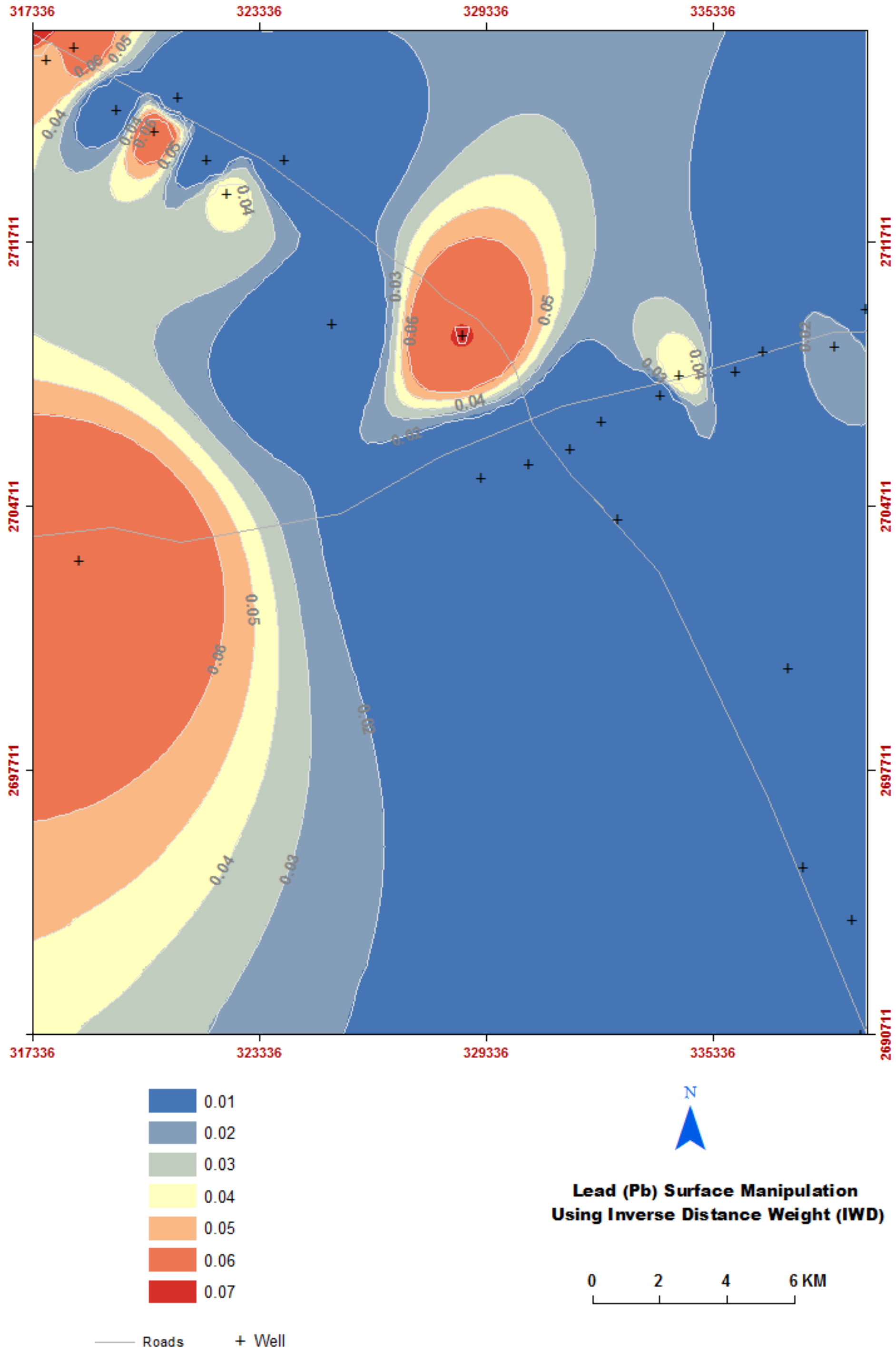

Figure 37: Contour map of Pb distribution of GW samples in the study area

4.5.3. Strontium (Sr)

Strontium is abundant in the earth. It is one of the alkaline earth metals. It is highly soluble in water and water-soluble solutions, and reacts strongly with oxygen. Strontium has similar physical and chemical properties of calcium and barium (Skougstad & Horr, 1963). Sr is found in nature in the forms of SO_4^{-2} mineral celestite ($SrSO_4$) and carbonate strontianite ($SrCO_3$).

Sr has the ability to attach to soil particles after weathering of rocks and moves with the particle and infiltrates into groundwater (Kulp, 1952). The WHO Guidelines (2011) has no standard level for strontium but the health advisory lifetime for strontium is set at 17.0 mg/l (Department of Natural Resources, 2002). The availability of sulphate and carbonate in the area allow Sr to present in high amounts.

Sedimentary fossils present in limestone contain strontium and huge amounts of sulphate and carbonate that can be easily react with strontium. As Sr, Ca^{+2}, and K^{+} are involved in ion exchange process; it allows Sr to exchange with K^{+} and $Ca^{+2}$and to stay in the groundwater of the study area (Hem, 1985). Sr is also associated with weathering of gypsum deposits in the area (Department of Natural Resources, 2002). In the study area, strontium varies between 4.6-46.6 mg/l. 18 samples out of 27 exceeded 17 mg/l. it is concentrated in the west part of the study area and have similar trend of sulphate and calcium (Figure 38).

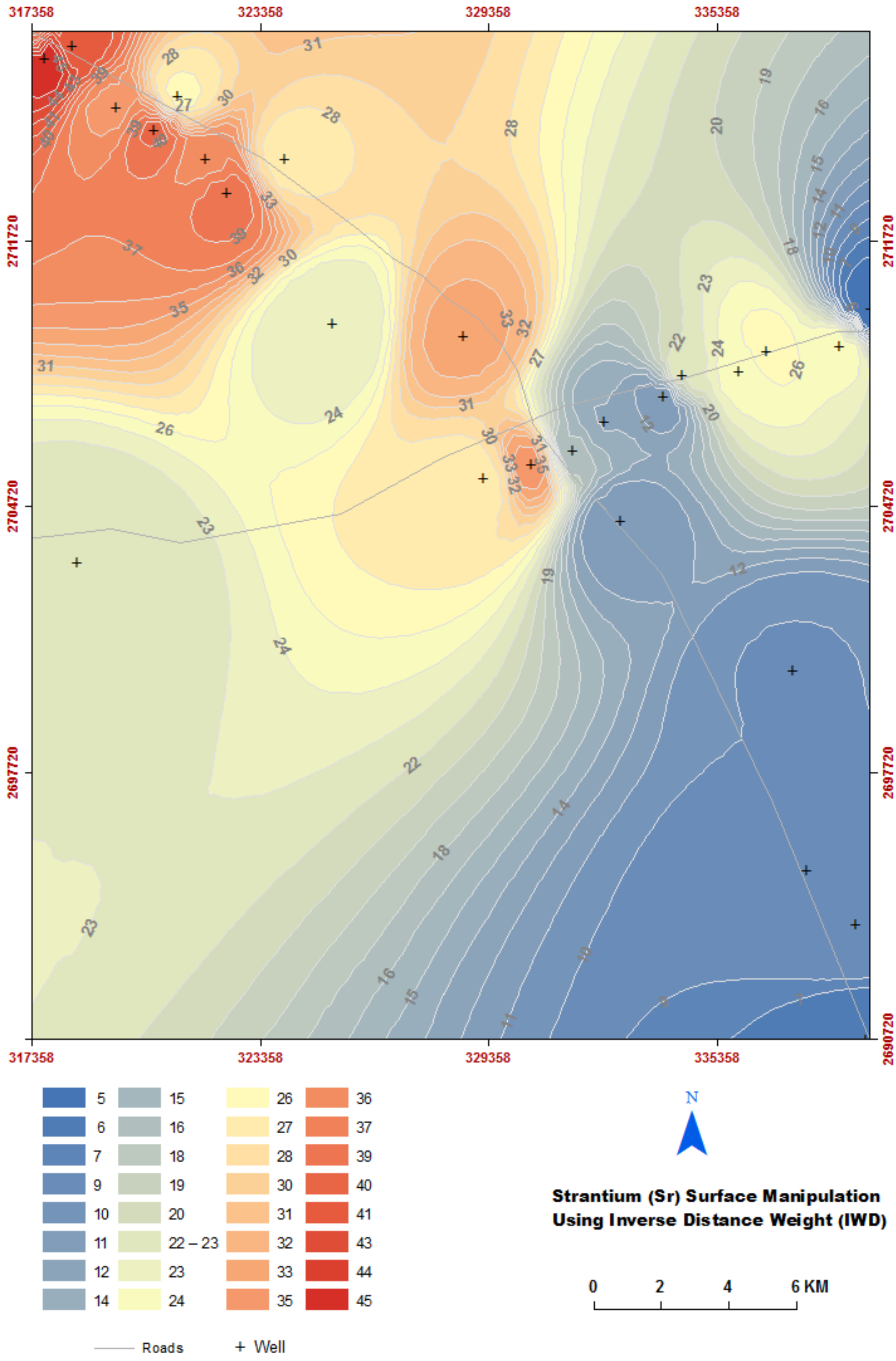

Figure 38: Contour of Sr distribution of GW samples in the study area

4.5.4. Hydrochemical Facies

The concept of hydrochemical facies is used to explain the different chemical characteristics of groundwater by dividing it into categories according to its chemical components, and to be able to propose the possible chemical processes and reactions occurred between water and its surrounding subsurface constituents including minerals.

Water types are the phrase used to describe hydrochemical facies. Water type is represented by the dominance of each anion/cation exceeding 50% of total anions/cations in meq/l%. Only anion/cation which calculated value (meq%) exceeded 15 is considered (Altoviski,1962). 27 samples were analysed from Sweihan area giving 7 different groupings which are:

1. Sodium -SO_4- Chloride (samples 1,3,4,5,7,8,10,12,13,17,27)
2. Mg-Sodium-SO_4-Chloride (samples 11,15,18,19,20,21,22,24,25,26)
3. Sodium-Cl-Sulphate (samples 2,6)
4. Ca-Sodium-SO_4-Chloride (samples 9,16)
5. Ca-Mg-Sodium-SO_4-Chloride (sample 14)
6. Mg-Sodium-Chloride (sample 23)

The dominance of all types is sodium and chloride except for two samples, which have sulphate as a dominant anion. Magnesium and calcium reveal the second order in samples 9,16,14,23. The dominance of sodium and chloride could indicate contamination of groundwater by agricultural practices. A process of reverse ion exchange of Na-Cl water originates from agricultural wastewater being mixed with groundwater. This emphasizes that agricultural practices in the study area affect the groundwater hydrochemistry heavily (Salman, 2013). In order to express water types in the study area, a trilinear diagram by Piper (1944) is plotted in (Figure 39).

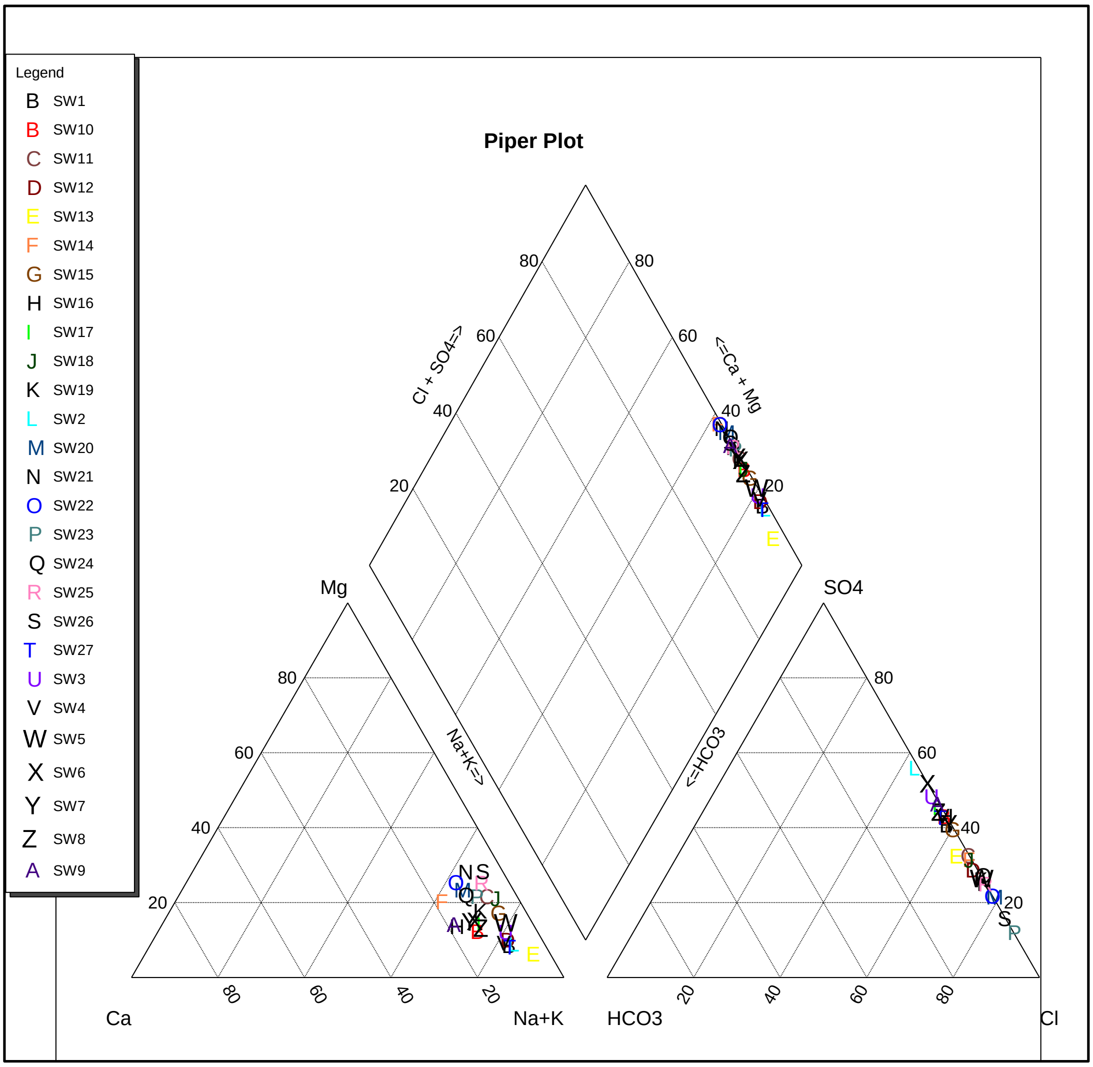

Figure 39: Piper diagram of the hydrochemical facies of GW samples in the study area

The principle of Piper diagram is a three-shaped illustration, two triangles and one diamond shape, where the triangles represent the cations (left triangle), whereas the anions (right triangle), and the diamond shape expresses the mixture of all anions and cations. However, Piper diagram has limitations that it only represents percentages of cations/anions regarding total concentrations without giving detailed information about water types present in the study area.

According to Piper diagram, the interpretation of the anions and cations are as following:

- All samples are settled in sodium and potassium type regarding cations concentrations.
- All samples are settled in chloride type except two samples settled in sulphate type regarding anions concentrations.
- Alkalis (Cl^- and SO_4^{-2}) are exceeded alkaline earth (Ca and Mg) by having chloride as the predominant anion followed by sulphate. The reason of chloride dominance is the contamination of agricultural wastewater water in the groundwater.
- Strong acids (sodium and potassium) exceeded weak acids (bicarbonate) by having sodium as the predominant cation. The reason for sodium dominance is the contamination of groundwater by agriculture effluents.

All the samples are located in the saline area of the diamond, ranging from 15-40, respectively, because the prevalent water type is sodium chloride, which attributes to other concentrations. Furthermore, all the samples are ling together indicating the similarity of compositions. In order to express the dominance of water types, a zonation map was created in as shown (Figure 40), showing Sodium-Chloride type as the predominant type followed by Sodium-Sulphate.

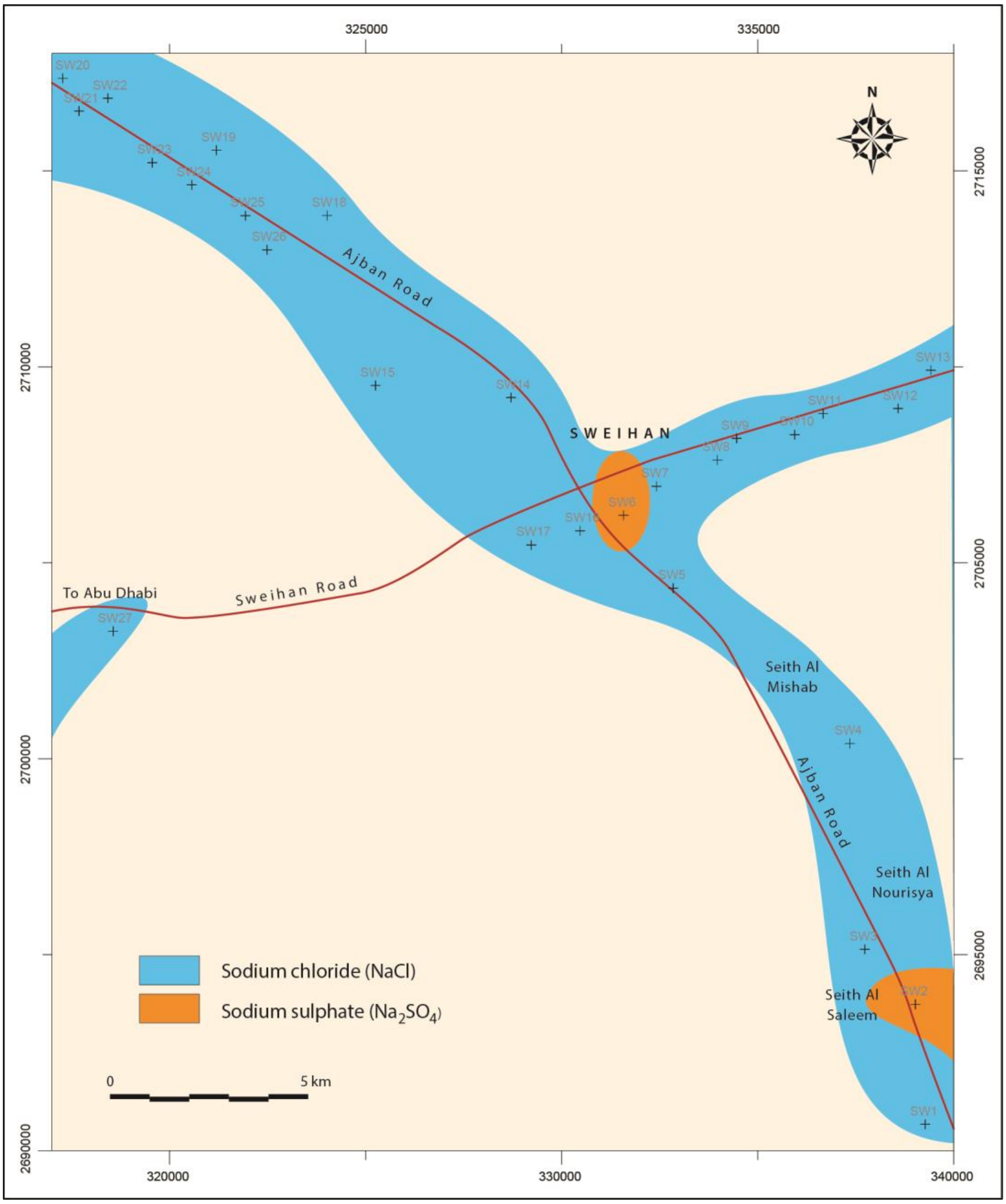

Figure 40: Zonation map of the dominant water type of GW samples in the study area

4.6. Water Genesis- Hypothetical Salt Combinations

Studying water genesis is essential in order to understand the chemical process that affect the water body. The analysis used by Sulin's principle is expressed by two equal squares. One square representing marine meteoric genesis including Na_2SO_4

and $NaHCO_3$, and marine water genesis including $CaCl_2$ and $MgCl_2$. Samples are expressed in milli equivalent percent and represented by meq% (Sulin, 1948).

Among the 27 samples collected, 8 samples are distinguished to be marine origin (samples 14, 19, 20, 21, 22, 23, 24, 25, 26), while the remaining 18 are of meteoric origin (samples 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 15, 16, 17, 18, 27). All marine origin ((Na/Cl)<1) samples are marine water origin of magnesium chloride ($MgCl_2$) permanent salt. It is calculated by (Cl-Na/Mg) < 1. It reveals that seven assemblages of salt combinations shown as following:

1. $NaCl > CaSO_4 > MgSO_4 > MgCl_2 > KCl > Ca(HCO_3)_2$ (well no.14)
2. $NaCl > MgSO_4 > CaSO_4 > MgCl_2 > KCl$ (wells no.24,19)
3. $NaCl > MgCl_2 > CaCl_2 > MgSO_4 > KCl > CaSO_4 > Ca(HCO_3)_2$ (well no.20)
4. $NaCl > MgSO_4 > MgCl_2 > CaSO_4 > KCl > Ca(HCO_3)_2$ (well no. 21)
5. $NaCl > MgCl_2 > CaSO_4 > MgSO_4 > KCl$ (wells no. 22)
6. $NaCl > MgCl_2 > CaSO_4 > MgSO_4 > KCl > Ca(HCO_3)_2$ (well no.23)
7. $NaCl > MgSO_4 > MgCl_2 > CaSO_4 > KCl$ (well no.25)
8. $NaCl > MgCl_2 > MgSO_4 > CaSO_4 > KCl$ (well no.26)

Samples are exist with permanent salts representing as $CaSO_4$ and $MgSO_4$ being $MgSO_4$ wider than $CaSO_4$ from the ascending order. Permanent salts may exist due to leaching processes of the rocks present in the area which are rich of sulphate minerals such as gypsum ($CaSO_4{\cdot}2H_2O$) and carbonate minerals such as dolomite ($CaMg(CO_3)_2$) which are rich in calcium and magnesium.

In addition, calcium and magnesium are having cation exchange processes through water-rock interaction from old marine origin (Abdellattif, 2003). The existence of $MgCl_2$ as the marine water origin in the study area indicates that the groundwater has gone through heavy pumping, which leads to dissolution of salt minerals of deep marine deposits and increase the concentrations of salts in the groundwater (Salman, 2013).

The second origin is meteoric water origin ($(Na/Cl)>1$) of sodium sulphate (Na_2SO_4) water type ($(Na\text{-}Cl/SO_4) < 1$) and accounting for 18 samples. It reveals the following hypothetical salt combinations:

1. $NaCl > Na_2SO_4 > MgSO_4 > CaSO_4 > KCl$ (wells no. 1,8)
2. $NaCl > Na_2SO_4 > MgSO_4 > CaSO_4 > KCl > Ca(HCO_3)_2$ (wells no. 3, 6, 12, 13, 17, 27)
3. $NaCl > Na_2SO_4 > MgSO_4 > KCl > CaSO_4$ (well no. 2)
4. $NaCl > Na_2SO_4 > MgSO_4 > CaCl_2 > KCl > Ca(HCO_3)_2$ (well no. 4)
5. $NaCl > MgSO_4 > Na_2SO_4 > KCl > CaSO_4$ (well no. 5)
6. $NaCl > MgSO_4 > CaSO_4 > Na_2SO_4 > KCl$ (wells no. 7,11)
7. $NaCl > CaSO_4 > Na_2SO_4 > MgSO_4 > KCl$ (well no. 9)
8. $NaCl > Na_2SO_4 > CaSO_4 > MgSO_4 > Ca(HCO_3)_2 > KCl$ (well no. 10)
9. $NaCl > MgSO_4 > Na_2SO_4 > CaSO_4 > KCl$ (well no. 15)
10. $NaCl > CaSO_4 > MgSO_4 > Na_2SO_4 > KCl > Ca(HCO_3)_2$ (well no. 16)
11. $NaCl > MgSO_4 > Na_2SO_4 > CaSO_4 > KCl > Ca(HCO_3)_2$ (well no. 18)

It is noticed that there are variety of salt assemblages, which indicates ion exchange processes in the study area. The wide range of permanent salts ($CaSO_4$ and $MgSO_4$) indicates presence of sulphate and carbonate minerals. The dominance of sodium in all water types and origin indicates the infiltration of meteoric water due to irrigation into the recharge basin (Abdellatif, 2003). A zonation map of the two origins is displayed showing the majority of meteoric origin of sodium sulphate water type (Figure 41). In addition, the trend of having marine origin magnesium chloride-water type concentrated in the northwest and west (samples 14, 19-26) of the area emphasizes the heaviest agricultural activities, which exists in the same area.

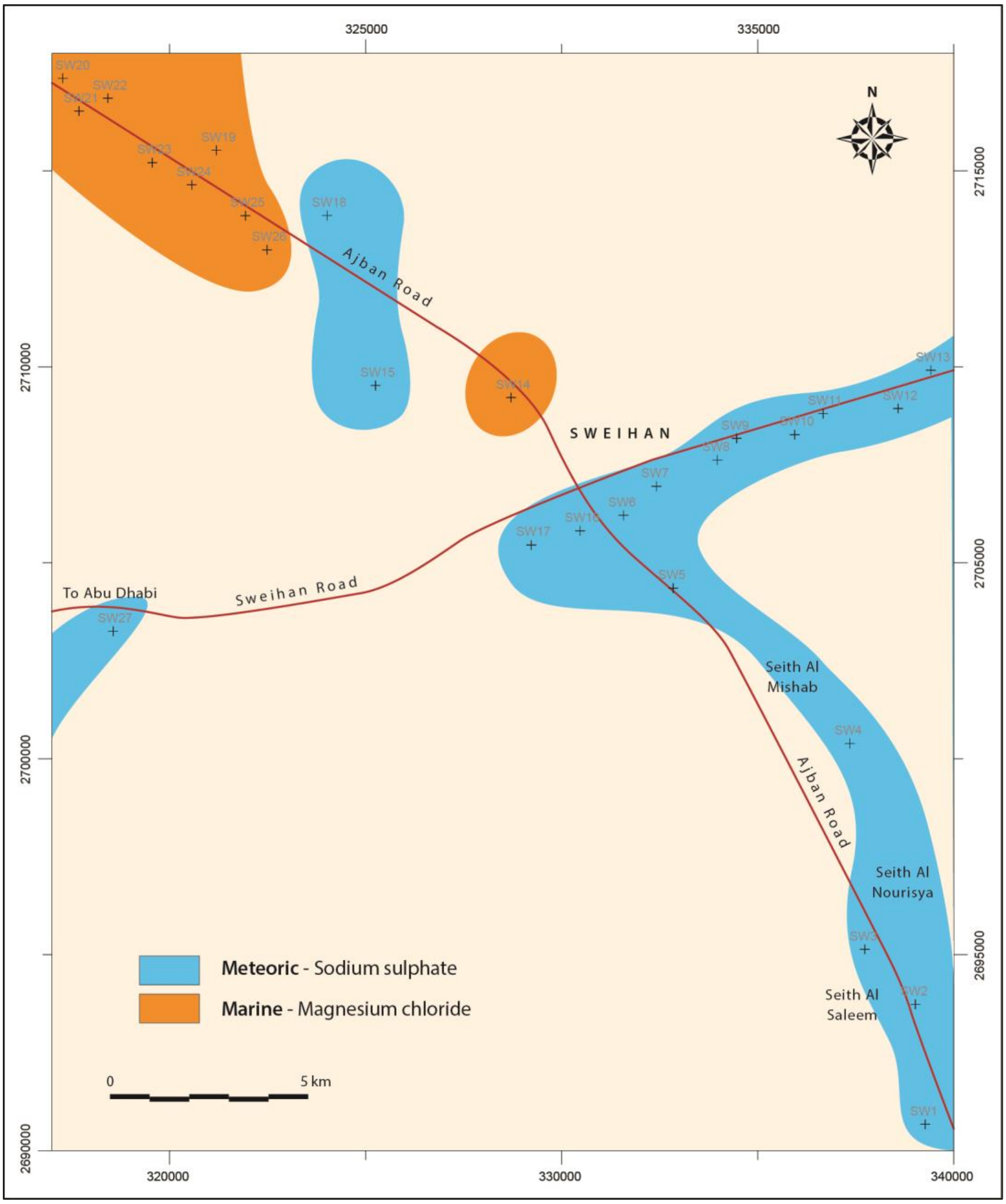

Figure 41: Zonation map of major water genesis of GW samples of the study area

4.7. Graphical Interpretations

As noticed from (Figure 42), the relationship between Na^+ and Cl^- are proportional for all samples. This diagram reaffirms that sodium and chloride are originates from the same source, which are agriculture activities.

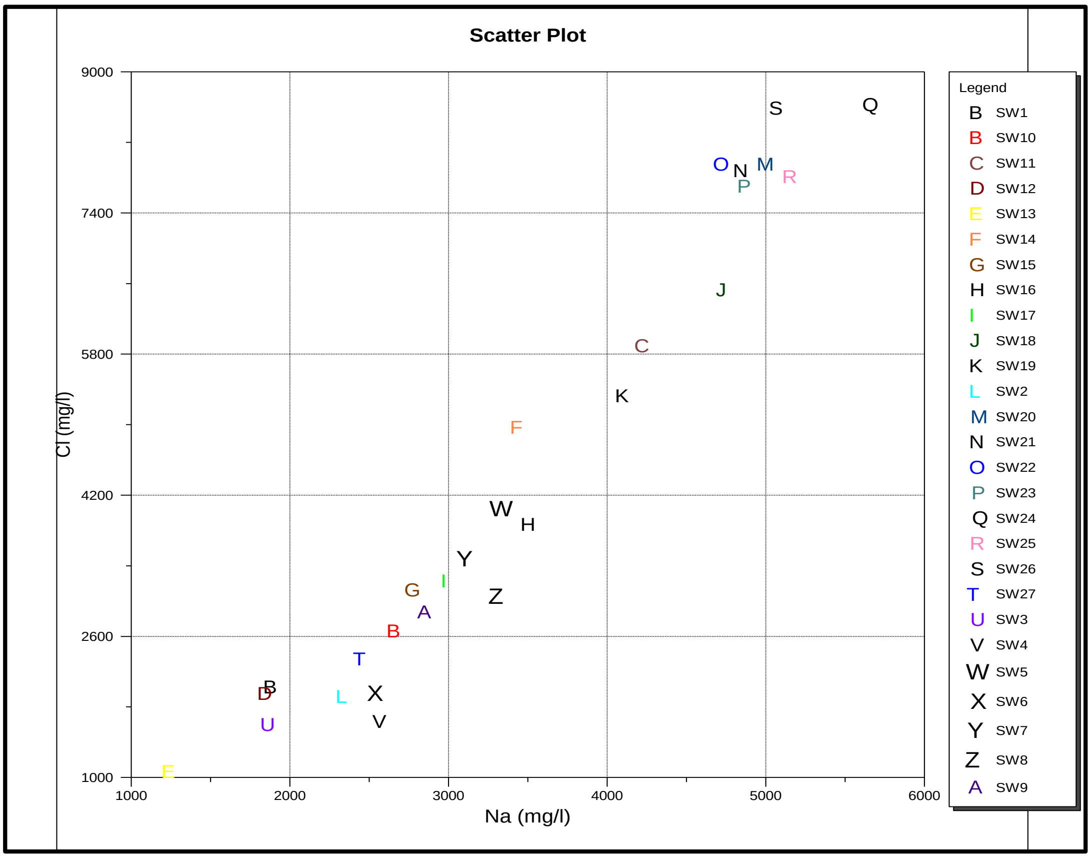

Figure 42: Relationship between Na^+ and Cl^- of GW samples in the study area

Ternary plot are used for showing the dominance of an ion in samples of a certain area. It is principle deals with the ratios of the three elements should at end equals to 100 (Rossi, 2000). From the graph (Figure 43) it is showed that the ratio of Na^+ is higher compared with other cations (Ca^{+2} and Mg^{+2}), which is within 80 – 95.

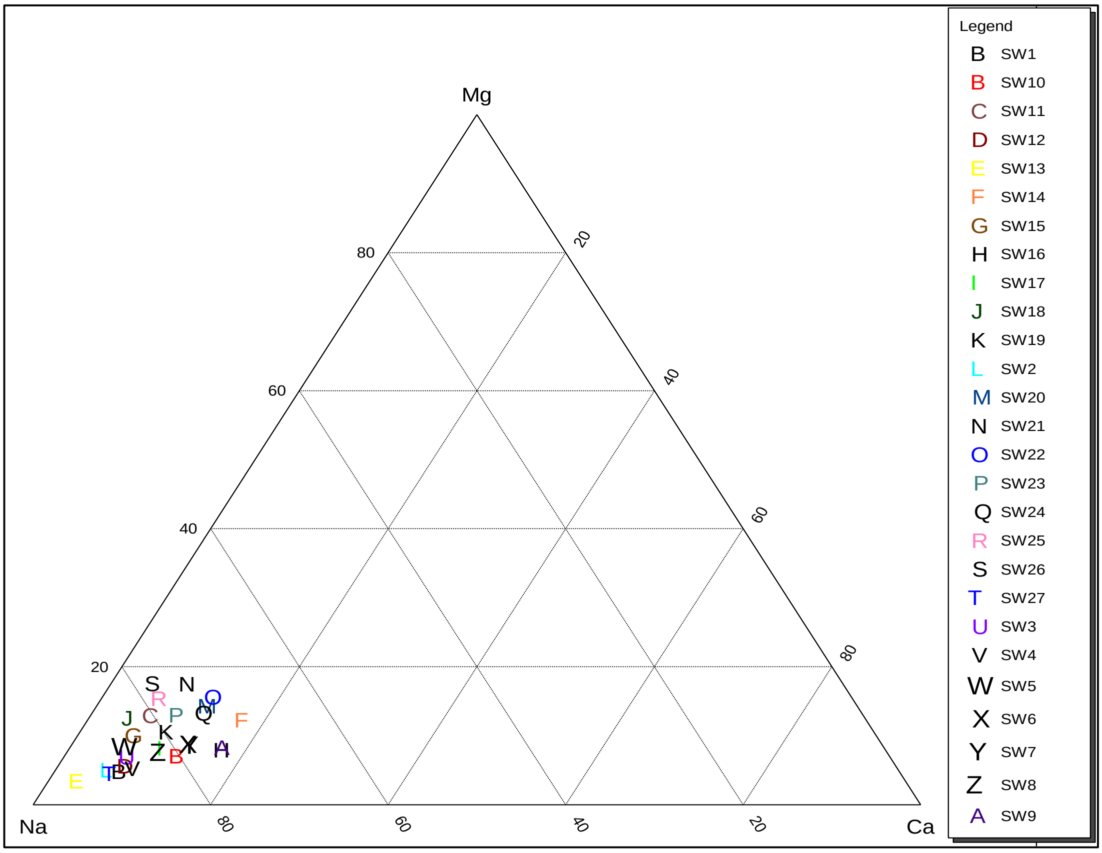

Figure 43: Ternary diagram of GW samples in the study area

Site map is another method of displaying hydrochemical results of groundwater samples. It is one of the pattern diagrams where symbols are used on the map. The upper half of the pie is expressing the cations and the lower half is expressing the anions. The pie size itself represents the TDS amounts in each sample. Each pie is expressing the whole concentrations of all cations and anions present in the sample in meq/l (Zaporozec, 1972).

In (Figure 44), it is shown that sodium concentration is highest in all samples compared with other cations. Chloride as well is the highest among other anions and taking the dominancy. The pie size for all samples is similar indicating the TDS values are at same ranges.

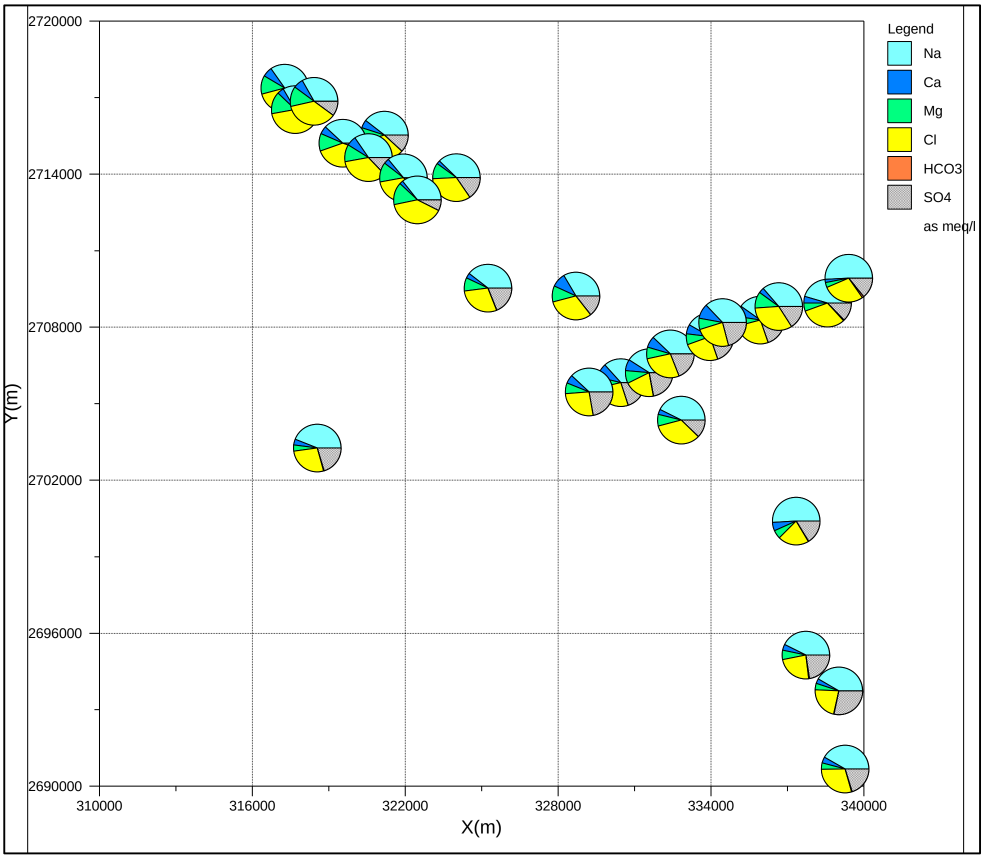

Figure 44: Site map of GW samples of the study area

4.8. Groundwater Quality

In order to use the groundwater f or domestic and irrigation practices, it should be analysed using number of criteria. Sweihan groundwater samples will be evaluated through four different methods. Total hardness (TH) is the first measurement discussed.

Calcium carbonate ($CaCO_3$) is used to measure hardness as calcium and carbonate is the highly soluble elements in water (Mohsen, 2013). Sodium Absorption Ratio (SAR) is another method used to evaluate groundwater. Na^+ is one of the important parameters to be measured for irrigation purposes. As sodium has adverse effects to water, soil and crops, it is measured with regard to magnesium and calcium (US Salinity Laboratory, 1954). Other methods used are sodium percentage (N%) and Magnesium Absorption Ratio (MAR). Each criterion will be discussed in detail below.

4.9. Total Hardness (TH)

Total hardness is an important measurement for determining the suitability of water for drinking, domestic and other industrial purposes. Traditionally, it is a measure of the ability of water to act with soap and produce a precipitate. Hard water is rich in dissolved minerals, both calcium and magnesium. As water moves through soil and rock, it takes these small particles of these naturally occurring minerals and carries them into the groundwater.

Hardness is caused by dissolved polyvalent metallic ions. Calcium and Magnesium are the role-playing, which exists in the form of CO_3^-, Cl^-, SO_4^{-2}, and NO_3^- (WHO guidelines, 2006). Hard water is not dangerous in terms of heath, but it affects the taste and purity of water. It also accumulates in pipes and affects the pressure of water causing scales in the pipes and municipal distributing systems. According to WHO Guidelines (2011), the maximum permissible level of hardness in drinking water is 200 mg/l based on the acceptability of water for drinking.

In this study, the TH values of water samples are in the range of 297.1-6439.6 mg/l. Referring to the classification of hardness, after *Raghunath,1990*, 0-60 mg/l is soft, 61-120 mg/l is moderately hard, 120-180 mg/l is hard, above 180 is very hard, 100 % (27) of samples are above the prescribed limit (>180 mg/l) for drinking water.

In Sweihan area, all CO_3^-, Cl^-, SO_4^{-2}, and NO_3^- are very high in concentration. As Ca^{+2} and Mg^{+2} concentrations are high in the region because of dissolution of dolomite and limestone, total hardness value is very high too (Murad, 2011). Therefore, the groundwater of Sweihan region is very hard and cannot be used for drinking or domestic uses.

4.10. Sodium Absorption Ratio (SAR)

Sodium is one of the most studied cations, because of its toxicity effects on crops and well-known effects on soil texture. High concentration of sodium disperses soil colloidal particles, causing the soil to be hard and resistant to water diffusion.

The osmotic pressure in the soil then builds up and causes complications in water to be absorbed by plant roots (Sherif, 2011). SAR is expressed as the formula (US Salinity Laboratory, 1954), *where* values of Na^{+}, Ca^{+2}, Mg^{+2} are in meq/l.

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

Equation 1: SAR calculation

The following (Table 5) shows the result of SAR and suitability for irrigation:

SAR	Classification	No. of wells (%)
1-10	Suitable for all types of crops and soil except those sensitive for sodium	0%
11-18	Suitable for coarse of textured or organic soil with permeability	0%
19-26	Harmful for almost all soil	30% (8)
>27	Unsuitable for irrigation	70% (19)

Table 5: Suitability of GW in Sweihan area for irrigation using SAR ratio

Groundwater of Sweihan region ratio for SAR ranges from 22 to 34.3 with an average of 28.6. High values are concentrated in the west part of the region where most of ions are concentrated. Moreover, 8 samples (30%) show a range from 19-26 and are harmful to use for irrigation practices, while 19 samples (70%) show they are not suitable for irrigation because they exceeded the ratio of 27.

Wilcox diagram, which is widely used for water stability regarding irrigation by comparing sodium ratio and electrical conductance. Respectively, Sodium ratio is categorized as S: *low*, S2: *medium*, S3: *high* and S4: *very high*, while electrical conductance, expressed as salinity, is classified as C1*: low*, C2: *medium*, C3: *high* and C4: *very high* (Wilcox, 1955).

By using these parameters, a Wilcox plot was constructed as shown in (Figure 45). The diagram demonstrates that all samples are out of range, except for one sample (No.13). Therefore, groundwater of Sweihan region cannot be used for irrigation as using it could harm the soil structure and plant production.

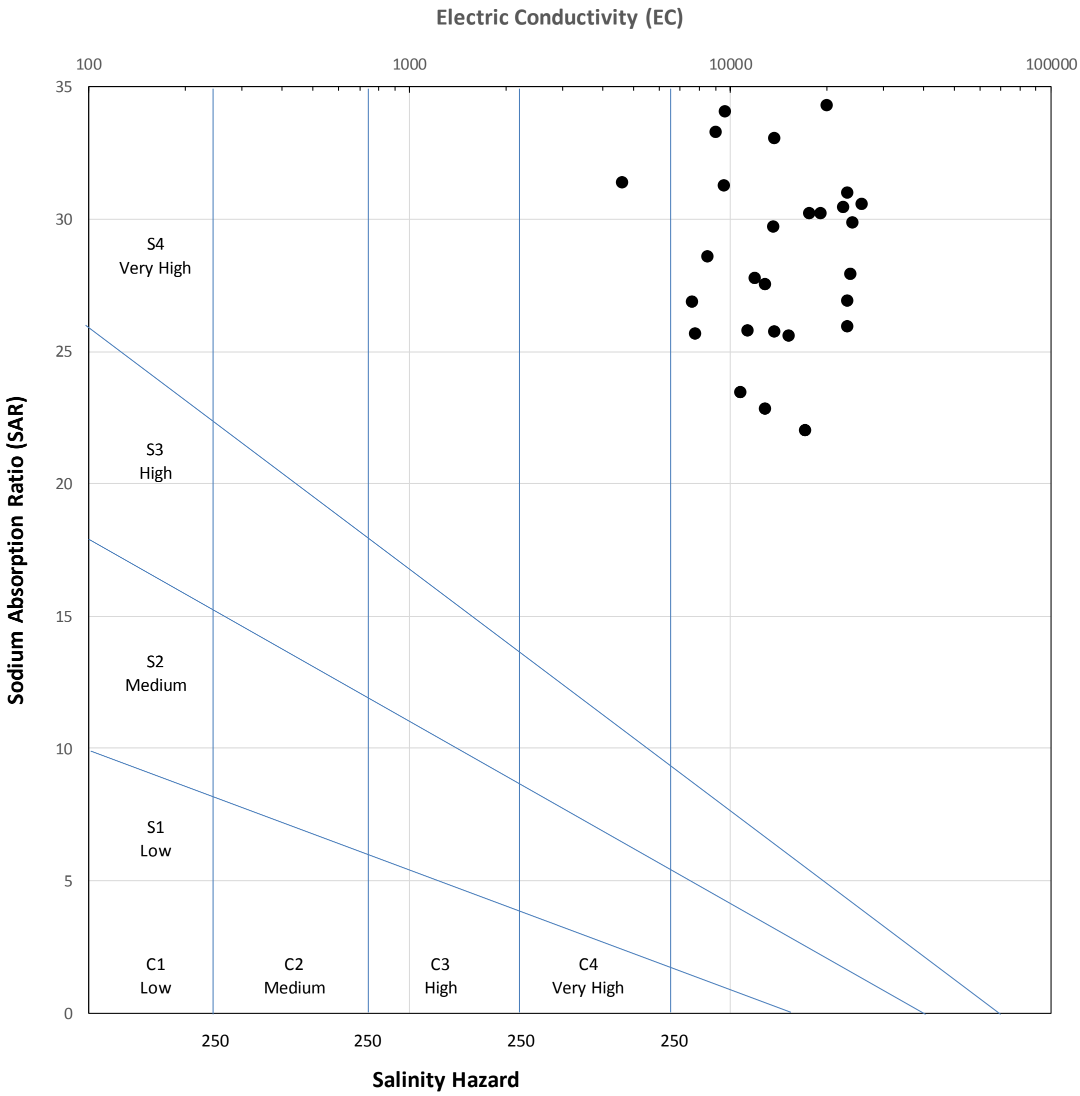

Figure 45: Wilcox diagram of GW samples in the study area

4.11. Sodium Percentage (Na %)

The Na percentage is the measurement of sodium content compared to the total cations in the sample. Sodium ion involves in cation exchange processes where sodium is taken up and magnesium and calcium are released into water. This process normally reaches the equilibrium continuously. If sodium increases than other ions, then soil disperses. When soil disperses, soil particles separate and sodium accumulate in plant tissues. This results in reduction of soil permeability and crop productivity (Chun-Ming, 2011).

Therefore, Na percentage is regarding other ions present using the following formula, (after Wilcox, 1955), whereas the values are classified in the (Table 5) below, as all concentrations are in meq/l.

$$\mathbf{Na}\ \% = \frac{(\mathbf{Na} + \mathbf{K})}{\mathbf{Na} + \mathbf{K} + \mathbf{Mg} + \mathbf{Ca}} \times \mathbf{100}$$

Equation 2: Na% calculation

Na%	Zones	No of wells
< 20	Excellent	-
20 - 40	Good	-
40 - 60	Permissible	-
60 - 80	Doubtful	21 (78%)
> 80	Unsuitable	6 (22 %)

Table 6: Shows Na% in various zones

According to above classification, Na percentage is very high in the study area. Twenty-one samples are located in the doubtful zone and six samples are located in the unsuitable zones. The results conclude that Na percentage in the study area is high, which means that the exchange process is not reaching the equilibrium. Hence, soil along with crops is affected negatively from sodium. Groundwater water of Sweihan is not suitable for irrigation uses (Yidana, 2010).

4.12. Magnesium Adsorption Ratio (MAR)

One of the important criteria of evaluating the quality of groundwater is the amount of Mg^{+2}. When Mg^{+2} content becomes high, the crop yields are affected as the soil increases its salinity (Joshi et al, 2009).

According to the ratio, (≥50) is suitable and (< 50) is unsuitable, using the following equation, where all the concentrations are in mg/l (Ayers & Westcot, 1985):

$$MAR = \frac{Mg \times 100}{Ca \times Mg}$$

Equation 3: MAR calculation

Values of MAR were found to be within the ranges from 0 to 2. This express that Sweihan region has good quality of groundwater to be used for irrigation regarding magnesium content.

4.13. Environmental Isotopes in Groundwater

Groundwater is one of the main components in the hydrological cycle and understanding its physical and chemical processes is essential. Isotopes studies are geochemical tools that provide good information about hydrogeological characteristics of aquifers including origin, time, and rate of recharge and interconnections within the aquifer. This helps in assessing and managing groundwater resources in better ways (Deshpande, 2003).

Isotopes are molecules that have same number of protons with different numbers of neutrons. Generally, stable isotopes of oxygen and hydrogen are commonly used to study groundwater origin. The most common isotopes used in this field are ^{18}O and ^{2}H or Deuterium (Richter, 1988). The abundance of ^{18}O is measured using the following formula (Craig, 1963):

$$\delta = \frac{\mathbf{R}\,\text{sample} - \mathbf{R}\,\text{standard}}{\mathbf{R}\,\text{standard}} \times 1000$$

Equation 4: ^{18}O & ^{2}H abundance calculation

Where δ is the relative, proportion presented by per mile (‰) and (R sample) is the isotopic ration of $^{18}O/^{16}O$ in the sample with respect to an internationally accepted standard (R standard). The international standard used is *Vienna Standard Mean Ocean Water* (VSMOW). When δ is positive, it means the sample is enriched, while the negative δ means the sample is depleted (Taylor, 2003).

The isotopic composition of groundwater in Sweihan showed more positive or enriched values than negative in $\delta^{18}O$ results, which indicates that Sweihan samples are enriched with ^{18}O, meaning that groundwater went through heavy evaporation periods. Table 7 displays the result of parameters ($\delta\,^{18}O$, δD, d-excess).

The $\delta^{18}O$, in the study area, ranges from -1.00 to 1.72 ‰ and δ D ranges from -5.7 to 4.3%. The varieties of values between δD and $\delta^{18}O$ indicate that there is more than one source of recharge of Sweihan groundwater (Price & Swart, 2006). Besides, it suggests that there is more than one source affecting the quality of groundwater. These sources are natural from dissolution of rocks and from human influence of agriculture input. (Figure 46) displays the isotopic composition of oxygen and hydrogen water compared to local meteoric water line (LMWL) for UAE (δD = 8

$\delta^{18}O$ + 15), where <8 for evaporation and >8 for condensation (Murad & Krishnamurthy, 2004).

ID	$\delta^{18}O$	δD	d-excess
SW1	0.06	-2.3	-2.8
SW2	-0.86	-5.7	1.2
SW3	-0.43	-3.1	0.3
SW4	0.81	-0.3	-6.8
SW5	1.01	-0.7	-8.8
SW6	0.54	-0.3	-4.6
SW9	1.00	0.9	-7.0
SW11	0.88	0.3	-6.7
SW13	-1.00	-5.4	2.6
SW14	1.14	2.1	-7.0
SW15	0.56	-1.2	-5.7
SW17	0.95	0.7	-6.9
SW20	1.72	4.3	-9.4
SW23	1.61	3.7	-9.2
SW27	0.26	-3.6	-5.7

Table 7: $\delta^{18}O$, δD, d-excess for GW samples in the study area

The regression line for Sweihan samples are ($\delta D = 3.5\ \delta^{18}O - 2.6$), which shows a slope of 3.5 and an intercept of -2.6. The slope of 3.5 shows non-equilibrium process when slope is under eight. This concludes that there are evaporation processes in the area and low rainfall (3.5<8). The small intercept of -2.6 compared with LMWL of 15, indicates that precipitation is very low comparing with the country as a whole (Hoefs, 1997).

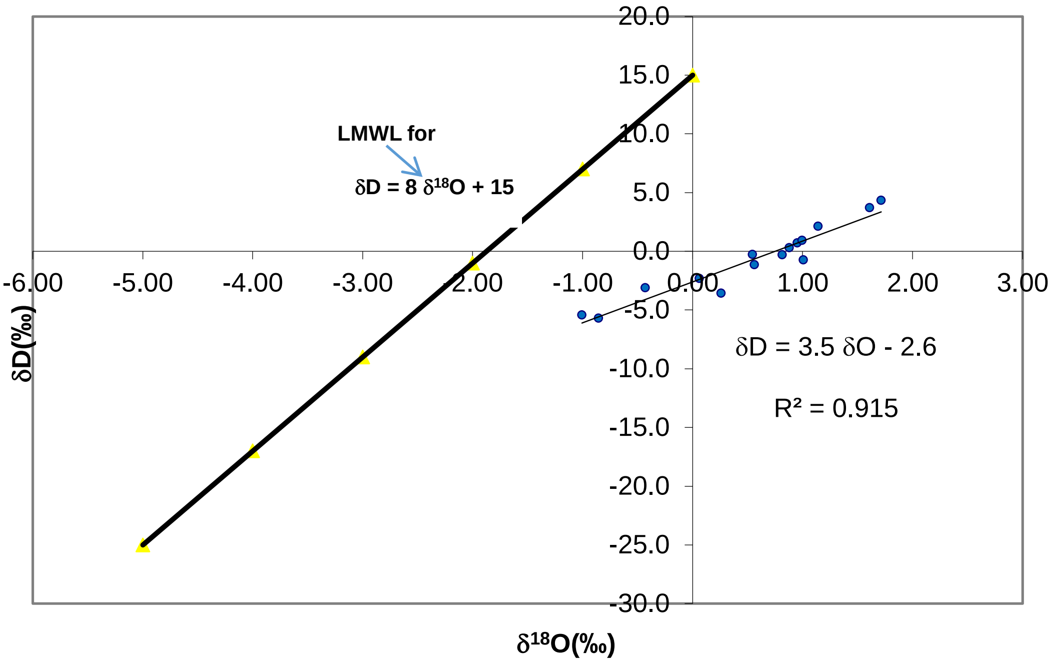

Figure 46: Regression line of δD - $\delta^{18}O$ of GW samples in the study area

Moreover, the water vapour in the samples are 3 times bigger for δD than for $\delta^{18}O$ compared with LMWL (3.5<8). Moreover, the intercept (+15) in the regression line indicates the precipitation from seawater. The intercept (-2.6) for Sweihan regression line expresses that Deuterium is depleted by 2.6 parts per thousand (per mil) relative to LMWL. The depletion of Deuterium is due to evaporation events (Price & Swart, 2006). By using d-excess, water vapour can be used to trace the source of local precipitation. D-excess is calculated by the following equation (Clark & Fritz, 1997; Dansgaard, 1964)

$$\mathbf{d = \delta D - 8\,\delta\,^{18}O}\ (‰)$$ **Equation 5:** D-excess calculation

Where d is the relative proportions of ^{18}O and ^{2}H contained in water and presented by per mile (‰).

The *d*-excess values in the study area ranges from -9.4 to 2.6 ‰. The *d*-excess of precipitation is below 15 (for LMWL), which indicates that the precipitation has been affected by the raindrop evaporation before reaching the ground, whereas the samples falling to the right of LMWL leading to low recharge flow (Foehlic et al, 2008; Murad et al., 2011).

The groundwater salinity could be evaluated by plotting the relationship between chloride, representing the salinity, and δD (Figure 47). The trend of increasing chloride concentration with enrichment of isotopic composition of H^+ suggests that the main source of the groundwater in the study area is evaporated raindrops (Cindrich & Gudmundssor, 1984; Murad et al., 2011).

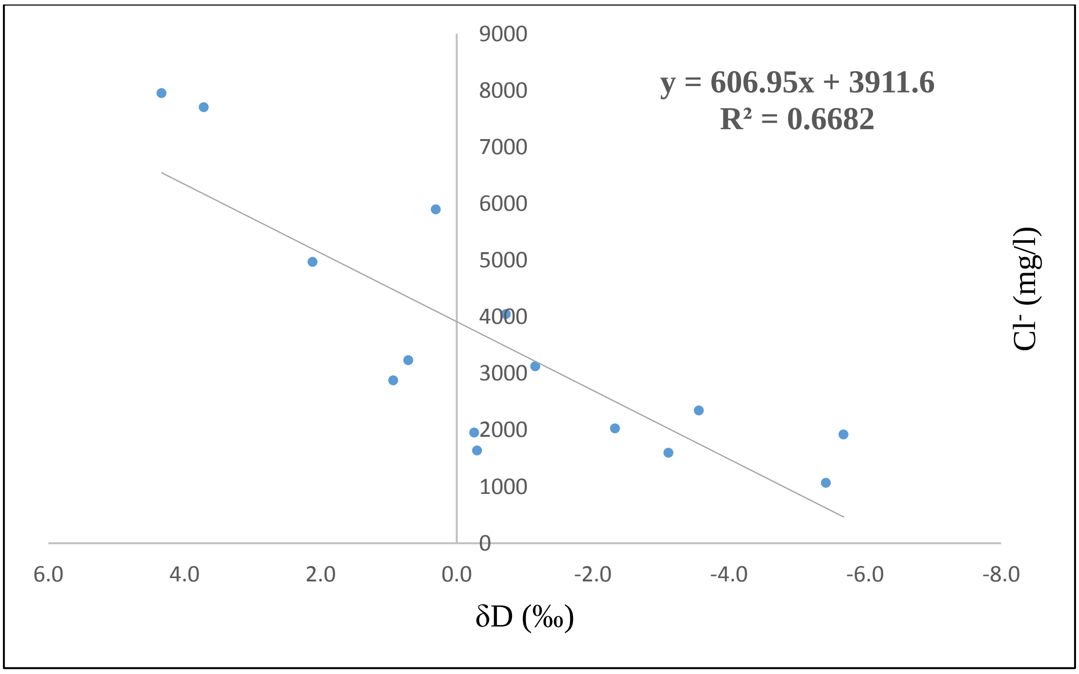

Figure 47: Relationship between Cl- concentration and ^2H isotopic composition for GW in the study area

In addition, the same relationship is plotted for Cl^- and *d*-excess (Figure 48). The relationship expresses the trend of decreasing of Cl^- with increasing of *d*-excess and the vice versa. It shows that increasing of salinity is affecting the recharge of groundwater negatively. It indicates that the effect is mainly by human resources other than natural resources including agricultural activities (N'Egrel et al., 2011).

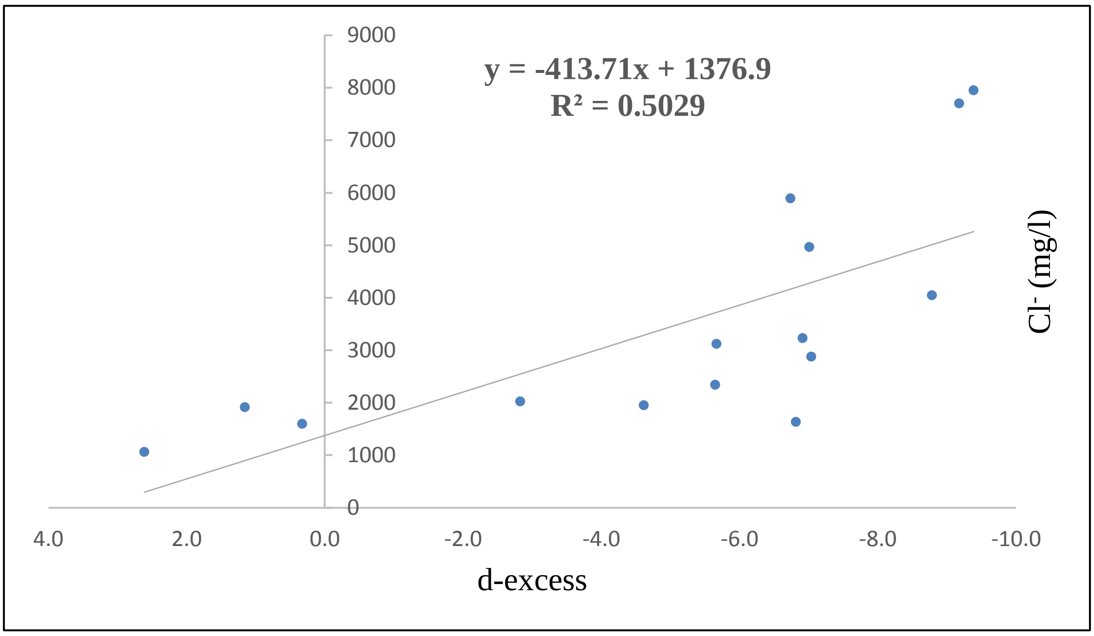

Figure 48: Relationship between Cl^- and d-excess of GW samples in the study area

CHAPTER FIVE

SUMMARY AND RECOMMENDATIONS

5.1. Summary

Abu Dhabi Emirate is characterized by high temperature periods and low rainfall amounts in summer and cool temperature with rainfall that could reach 77 mm in winter. Water resources of Abu Dhabi Emirate categorized of conventional water resources including groundwater, wadis flow, and some springs and non-conventional water resources including desalinated water and treated wastewater.

Groundwater of Abu Dhabi is suffering from deterioration and contamination due to low precipitation amounts and low recharge levels with high consumption. These factors lead to threaten the groundwater quality and quantity in the area. The main sector of using groundwater in the Emirate is the agricultural sector. The Eastern Region and Western Region in the Emirate are famous of agriculture using the groundwater as the main source for water supply. Nowadays, groundwater scarcity has led farmers to use desalinated water as alternative to satisfy these needs. In addition, the Emirate started to use wastewater for irrigating parks, roadsides and landscapes, but the uses are very limited due to social issues.

Sweihan region, which is located in the northeast of UAE country and northeast of Abu Dhabi Emirate, has about 275, farms producing different types of crops. As Sweihan depends on groundwater mainly for irrigation, quality and quantity measurements should be applied. Previous studies of the area concluded high salinity, and heavy metals contamination in the groundwater of the area, which become a health hazard.

The current study assesses the groundwater quality using physical properties, chemical properties and hydrogen and oxygen isotopes testing. The study showed high amounts of TDS reaching 2,938 to 16,384 mg/l. High salinity deriving from high TDS values were observed in all samples in the area. The main reasons of high TDS values are high anions and cations present in the groundwater due to high agriculture activities and heavy pumping of groundwater with no balance of recharge leading to increasing of salts accumulation.

The cations present in the groundwater samples took an order of Na^{+} > Mg^{+2} > Ca^{+2} > K^{+}, while anions took an order of Cl^{-} > SO_4^{-2} > HCO_3^{-} > NO_3^{-}. The dominance of all ions was sodium and chloride, followed by magnesium, calcium and sulphate. The groundwater in the area was shown to have two water origins, which are paleo-marine origin of magnesium chloride and meteoric water origin of Na_2SO_4 water type. The analysis showed the dominance of sodium and chloride in the area due to agricultural effluents, which gives good reasoning of high salinity in the studied area.

Groundwater quality was evaluated using the WHO guidelines in drinking (2011) for domestic use suitability and SAR, TH, Na% and MAR parameters were implemented for evaluating the groundwater suitability to be used for agriculture consumption. Analysis showed that the groundwater is not suited for either domestic use due to high amounts of cations, anions, and heavy metals that have health risk.

In addition, the groundwater was found to be not suitable for irrigation and another water source should be used, or groundwater should be treated before using. Hydrogen and oxygen isotopes regression line with comparison to local meteoric water line showed that the groundwater has gone through many evaporation processes, leading to high salinity due to low recharge. The chloride relation with deuterium and d-excess suggests that there are many sources of groundwater salinity in the area.

5.2. Recommendations

Environmental authorities and governmental agencies regarding groundwater reservation have implemented many efforts. Many areas are now under to better understand the groundwater behaviour in the area and find better management regulations.

Agriculture sector should be managed better to have sustainable groundwater consumption. For better management, government should:

1. Develop water resources strategic plan
2. Implement of strict rules regarding pumping of groundwater and unplanned drilling of wells.
3. Implement strict rules for using fertilizers based on their quantities and types.
4. Monitor the groundwater resources will help better understanding the limitations for better use.
5. Education should be applied including farmers and farm owners of health hazards present by using wrong practices.
6. Public awareness is important for future sustainability of water resources

Bibliography

Abdel-Lattif, A. (2003). Groundwater chemistry of the shallow aquifer, El-Tur area, South Sinai, Egypt. *Journal of Environmental Hydrology, 11*(1), 1-16.

Abu Dhabi Food Control Authority. (2012). *Annual report 2013*. Retrieved 13, September, 2014, https://www.adfca.ae/Arabic/Publications/Pages/mta.aspx

Abu Dhabi Food Control Authority. (2011). *Statistics Book 2011*. From: https://www.adfca.ae/Arabic/Publications/Pages/mta.aspx (Sept. 13, 2014)

Abu Zaid, M. M., Baghdady, A. R., & El Etr, H. A. (2001). Textural attributes mineralogy and provenance of sand dune fields in the greater Al-Ain area, United Arab Emirates. *Journal of Arid Environments, 48,* 475-499.

Arumugan, K., & Elangovan, K. (2009). Hydrochemical characteristics and groundwater quality assessment in Tirupur region, Coimbatore District, Tami Nadu, India. *Environmental Geology*, *58*, 1509-1520.

ADFCA. (2005). Assessment of groundwater quality in areas surrounding Al-Ain. *Soil and water Alsalamat laboratory*. Abu Dhabi Food Control Authority. Unpublished paper.

Ahmed, E. A., Soliman, M. A., Alsharhan, A. S., & Tamer, S. (1998). Mineralogical characteristics of the Quaternary sand dunes in the eastern province of Abu Dhabi, United Arab Emirates. (pp.85-90) in *Quaternary deserts and climatic change*. Al-sharhan, Glennie, Whittle, and Kendall (Ed.). (Rotterdam: Balkema).

Al-Hosani, M.; Ed. (2010). *Water Demand Forecast and Management of United Arab Emirates* (2000-2010), pp. 282-289.

Ali, Z., Malik, R. N., & Qadir, A. (2013). Heavy metals distribution and risk assessment in soils affected by tannery effluents. *Chemistry and Ecology*, *29*(8), 676-692.

American Farm Bureau Federation. (1987). *Water quality self-help checklist: American Farm Bureau Federation pamphlet*. Washington, DC: The Bureau.

Allison, L. E., Bernstein, L., Bower, C. A., Brown, J. W., Fireman, M., (…), & Wilcox, L. V. (1954). In L. A. Richards (Ed.): *Diagnosis and improvement of saline and alkali soils*. (Agriculture Handbook; no. 60) from: www.ars.usda.gov/sp2UserFiles/Place/53102000/.../hb60complete.pdf (Sept. 6, 2014).)

Alsharhan, A. S., Ahmed, E. A., & Tamer, S. (1998). Textural characteristics of Quaternary sand dunes in the Eastern Province of Abu Dhabi, United Arab Emirates. (pp.91- 108) in *Quaternary deserts and climatic change*. Al-sharhan, Glennie, Whittle, and Kendall (Ed.). (Rotterdam: Balkema).

Alsharhan, A. S., Rizk, Z. S., Nairn, A. E. M., Bakhit, D. W., & Alhajari, S. A. (2001). *Hydrogeology of an Arid Region: The Arabian Gulf and Adjoining Areas*: Elsevier Publishing Company, 331 p.

Altoviski, M. E. (1962). *Dictionary for Hydrgeologist. Gosgeolitchizdat*, Moscow, USSR, (in Russian), 616. [Abstract]

Al-Zubari, W. K. (1998). *Water Resources Management Issues and Challenges in the Gulf*. Cooperation Council Countries: Four Scenarios. Retrieved November 13, 2014, www.kysq.org/docs/AlZubari.doc

Aquastat. (2008). *United Arab Emirates*. Country profile. FAO. From: http://www.fao.org/nr/water/aquastat/countries_regions/ARE/index.stm (Sept. 15. 2014)

Assaf, S., Nour, M. (2014). Potential of energy and water efficiency improvement in Abu Dhabi's building sector. Analysis of Estidama Pearl Rating System. *Renewable Energy*, 1-8.

Atekwana, E. A., Atekwana, E. A., Rowe, R. S., Werkema Jr, D. D., & Legall, F. D. (2004). The relationship of total dissolved solids measurements to bulk electrical conductivity in an aquifer contaminated with hydrocarbon. *Journal of Applied Geophysics, 56*, 281-294.

Ayers, R. S., Westcot, D. W. (1985). *Water quality for agriculture*. *FAO Irrigation and Drain*. *29*(1), 1-109.

Battelle. (1999). *Background Report on Fertilizer Use, Contaminants and Regulations*. Washington, DC: US Environmental Protection Agency. 20460.

Bouwer, Herman. 1978. *Groundwater Hydrology*: New York. McGraw – Hill. 480p.

Bollaci, D., Hawkins, C., Mankin, J., & Wurden, K. (2010). *Sustainable water management, assessment and recommendations for the Emirate of Abu Dhabi*. Reported for the Abu Dhabi Urban Planning Council. New York: Colombia University, School of International and Public Affairs. 127p. http://mpaenvironment.ei.columbia.edu/files/2014/06/AbuDhabiFinalReport.pdf

Brook, M. C., et al. (2006) Groundwater Resources; Development and Management in Abu Dhabi Emirate, UAE. In: *Proceedings of 3rd Joint UAE-Japan*

Symposium, Sustainable GCC Environment and Water Resources, EWR, 2006. http://www.ead.ae [Online]

Brown, M.A. (1980). Textural and geochemical evidence for the origin of some chromite deposits in Oman ophiolite (p.714-721). In A. Panayiotou (Ed.): *Ophiolites, Proceedings of the International Ophiolite Symposium 1979*. Geological Survey, Cyprus.

Chapman, D., & Kimstach, V. (1996). Chapter 3: selection of water quality variables. *Water Quality Assessments - A Guide to Use of Biota, Sediments and Water in Environmental Monitoring*- 2nd Edition. Deborah Chapman (Ed.). UNESCO/WHO/UNEP.

Chilton, J. (1996). Chapter 9: groundwater. *Water Quality Assessments - A Guide to Use of Biota, Sediments and Water in Environmental Monitoring* - Second Edition. Deborah Chapman (Ed.). 1992, 1996. UNESCO/WHO/UNEP.

Choi, B., Yun, S., Mayer, B., & Kim, K. (2011). Sources and biogeochemical behavior of nitrate and sulfate in an alluvial aquifer: hydrochemical and stable isotope approaches. *Applied Geochemistry, 26*, 1249-1260.

Chun-Ming, C., Chang-Wei, Z., Xiao-Jing, S., & Zhi-Chun, W. (2011). Estimating exchangeable sodium percentage from sodium adsorption ratio of salt-affected soil in the Songnen Plain of Northeast China. *Pedosphere, 21*(2), 271-276.

Cindrich, R. B., & Gudmundssori, J. S. (1984). *Application of Stable Isotope 'Techniques to Tracing Recharge of Geothermal Systems on the Reykjanes Peninsula in Iceland*. Stanford Geothermal Program, Engineering and Earth Sciences, Stanford University, Stanford, California. SGP-TR-79.

Clark, I.D., Fritz, P. (1997). *Environmental isotopes in hydrogeology*, CRC Press, Boca Raton, 328 p.

Craig, H., Gordon, L. I., & Horibe, Y. J. (1963). Isotopic exchange effects in the evaporation of water. *Journal of Geophysics Research, 68*, 5079-5087.

Dansgaard, W. (1964). Stable isotopes in precipitation. *Tellus, 16*, 436–468.

Dawoud, M.A. (2008). *Water resources in Abu Dhabi Emirate, United Arab Emirates*. Environment Agency. Agedi program. Retrieved September, 14, 2014, www.agedi.ae/Pages/pdf/4%20Water%20Resources.pdf

Department of Natural Resources. Estate of Indiana. (2002). Groundwater quality chapter. *Groundwater resources availability, West Fork and White River*

Basin. White and West Fork White River Basin, p.34-112. Available online http://www.in.gov/dnr/water/4103.htm

Deshpande, R. D., Bhattacharya, S. K., Jani, R. A., & Gupta, S. K. (2003). Distribution of oxygen and hydrogen isotopes in shallow groundwater from Southern India: influence of a dual monsoon system. *Journal of Hydrology, 271*, 226-239.

Environmental Agency Abu Dhabi *EAD*. (2006). *Abu Dhabi Emirate water resources. Statistics 2006*. Environment Agency Abu Dhabi.

EAD. (2011). *Environmental atlas of Abu Dhabi Emirate*. Environment Agency of Abu Dhabi, Agedi. Developed by Crop Station. https://www.environmentalatlas.ae/ (Sept. 10, 2014)

EAD, (2014). *Groundwater* http://www.ead.ae/know-your-environment/groundwater/ (Sept. 14, 2014)

Edmunds, W. M., Guendouz, A. H., Mamou, A., Moulla, A. S., Shand, P., & Zouari, K. (2003). Groundwater evolution in the continental intercalaire aquifer of Southern Algeria and Tunisia: trace element and isotopic indicators. *Applied Geochemistry, 18*, 805-822.

Egbunike, M. (2007). Hydrogeochemical analysis of water samples in Nando and Environs of the Anambra Basin of South Eastern Nigeria. *The pacific journal of science and technology, 8*(1), 32-35.

El-Mahmoudi, A. S., Murad, A. A., & Suliman, S. Y. (2008). Geophysical and hydrochemical investigations of Al-Foah area, UAE. *Journal of Environmental Sciences, 36*, 1-28.

Environmental monitoring systems laboratory. *Method 200.7*. Revision 4.4. (EMMC version).

EPA. (2009). National primary drinking water regulations. *U.S. Environmental Protection Agency*.

Foehlic, K., Kralik, M., Papesch, W., Rank, D., Scheifinger, H., & Stichler, W. (2008). Deuterium excess in precipitation of Alpine regions – moisture recycling. *Isotopes in Environmental and Health Studies, 44*(1), 61-70.

Garamoon, H. K. (1996). *Hydrogeological and geomorphological studies on the Abu Dhabi-Dubai-Al Ain triangle, UAE*. Unpublished Ph.D. thesis, Geology Department, Faculty of Science, Ain Shames University, Egypt, 127 p.

Glennie. K. W., & Singhvi, A., K. (2002). *Event stratigraphy, palaeoenvironment and chronology of SE Arabian Deserts. Quaternary Science Reviews* (Special Issue).

Godgul, G. and Sahu, K.C. (1995). Chromium contamination from chromite mine, *Environmental Geology, 25*(4), 251–257.

GTZ/Dornier Consult/ADNOC. (2005b). Combined Artificial Recharge and Utilization of the Groundwater Resource in the Greater Liwa Area. *Pilot Project*. Final Technical Report.

Gupta, P., Choudhary, R., & Vishwakarma, M. (2009). Assessment of water quality parameters of Kerwa Dam for drinking suitability. *International Journal of Theoretical & Applied Sciences, 1*(2), 53-55.

Harter, T. (2003). *Groundwater quality and groundwater pollution.* Reference sheet 11.2 for Farm Water Quality Planning series (FWQP). University of California. Publication 8084.

Hem, J. D. (1985). *Study and Interpretation of the Chemical Characteristics of Natural Water*. Third edition. U.S. Geological Survey Water-Supply Paper 2254.

Henrie, T. D., Simion, V., Auckly, C., & Weber, J. V. (2002). Chromium 6+ concentrations in drinking water wells and the effects of chlorination. [Poster] *Conference of the CA-NV American Water Works Association*.

Hoefs, J. (1997). *Stable Isotope Geochemistry*, fourth edition, Springer-Verlag, Berlin Heidelberg, Germany, pp. 38 and 41-41.

Hunting geology and geophysics. (1979). *Geological map of the United Arab Emirates*. 1:500 000 scale. Borehamwood, UK.

Imes, J., & Tawfiq, I. (2009). Results of long-term aquifer test conducted near Sweihan, Abu Dhabi Emirate, to assess the sustained yield capability of the shallow aquifer. *Technical series administrative report*. National drilling company.

Jamshidzadeh, J., & Mirbagheri, S. (2011). Evaluation of groundwater quantity and quality in the Kashan Basin, Central Iran. *Desalination, 270*(1), 23-30.

Joshi, D. M., Kumar, A., & Agrawal, N. (2009). Assessment of the irrigation water quality of River Ganga in Haridwar District India. *Journal of Chemistry, 2*(2), 285 – 292.

Juned, S. A., & Arjun, B. B. (2011). Analysis of chlorides, sodium and potassium in groundwater samples of Nanded City in Mahabharata, India. *European Journal of Experimental Biology, 1*(1), available [online]

Kulp, J. L., Turekian, K. K., and Boyd, D. W. (1952). Strontium content of limestone and fossils: *Geological Society of America Bulletin, 63*, 701-716.

McDonnell, R.A. (2014). Circulations and transformations of energy and water in Abu Dhabi's hydrosocial cycle. *Geoforum, 57*, 225-233.

Mohamed, A. M. O. (2006). *Arid Land Hydrogeology: In Search of a Solution to a Threatened Resource:* Proceedings of the Third Joint UAE-Japan Symposium on Sustainable GCC Environment and Water Resources (EWR2006), 28 - 30 January 2006, Abu Dhabi, UAE (Volume IV in DARE series). CRC Press. 185p.

Mohamed, M. M. (2014). *An integrated water resources management strategy for Al-Ain City, United Arab Emirates*. Evolving Water Resources Systems: Understanding, Predicting and Managing Water–Society Interactions. Proceedings of ICWRS 2014, Bologna, Italy, June 2014 (IAHS Publ. 364, 2014), pp. 273-278.

Mohan, B. S., & Hosetti, B. B. (1998). Lead toxicity to Salvinia natans grown in macrophyte ponds. *Journal of Ecotoxicology & Environmental Monitoring, 8*(1), 03-07.

Mohsin, M., Safdar, S., Asghar, F., Jamal, F. (2013). Assessment of drinking water quality and its impact on residents' health in Bahawalpur City. *International Journal of Humanities and Social Science, 3*(15), 114-128.

Monjerezi, M., Vogt, R. V., Aagaard, P., & Saka, J. D. K. (2012). The hydro-geochemistry of groundwater resources in an area with prevailing saline groundwater, lower Shire Valley, Malawi. *Journal of African Earth Sciences, 68*(1), 67-81.

Murad, A.A. (2010). An overview of conventional and non-conventional water resources in arid region: assessment and constrains of the United Arab Emirates (UAE). *Journal of Water Resources and Protection, 2* (2), 181-190.

Murad, A., Garamoon, H., Hussien, S., Al-Nuaimi, H.S. (2011). Hydrogeochemical characterization and isotope investigations of a carbonate aquifer of the northern part of the United Arab Emirates. *Journal of Asian Earth Sciences, 40*, 213-225.

Murad, A. A., & Krishnamurthy, R. V. (2004). Factors controlling groundwater quality in Eastern United Arab Emirates: a chemical and isotopic approach. *Journal of Hydrology*, *286*(1), 227-235.

National Center of Meterology and Siesmlogy. (2011). *Climate of Sweihan*. http://new.ncms.ae/climate/climateData.asp?id=3 (October, 10, 2014)

Negrel, P., Pauwels, H., Dewandel, B., Gandolfi, J. M., Mascré, C., & Ahmed, S. (2011). Understanding groundwater systems and their functioning through the study of stable water isotopes in a hard-rock aquifer (Maheshwaram watershed, India). *Journal of hydrology*, *397*(1), 55-70.

Nelson, D. (2002). *Natural variations in the composition of groundwater*. Drinking water program. Oregon Department of Human Services. Springfield, Oregon. Presented at groundwater foundation annual meeting, November 2002. Retrieved November 2, 2014, https://public.health.oregon.gov/HealthyEnvironments/DrinkingWater/SourceWater/Documents/gw/chem.pdf

Niu, H. Y., Deng, W. J., Wu, Q. H., & Chen, X. G. (2009). Potential toxic risk of heavy metals from sediment of the Pearl River in South China. *Journal of Environmental Sciences*, *21*(8), 1053-1058.

Obiefuna, G., & Sheriff, A. (2011). Assessment of shallow groundwater quality of Pindiga Gombe area, Yola area, NE, Nigeria for irrigation and domestic purposes. *Research Journal of Environmental and Earth Science*, *3*(2), 131-141.

Oram, B. (2014). *pH in the environment, water research watershed*. Retrieved September 16, 2014, from http://www.water-research.net/index.php/ph-in-the-environment

Panno, S. V., Hackley, K. C., Hwang, H. H., Greenberg, S. E., Krapac., I. G., & Landsberger, S., O'Kelly,D.J. (2006). Characterization and identification of Na-Cl sources in groundwater. *Groundwater*, *44*(2), 176-187.

Piper, A. M. (1953). A Graphic procedure in the geochemical interpretation of water analysis. *US Geological Survey, Groundwater*, Note 12.

Price, R. M., & Swart P. K. (2006). *Geochemical indicators of groundwater recharge in the surficial aquifer system, Everglades National Park, Florida, USA*. *Geological Society of America* (Special paper) *404*, 251-266.

Raghunath, H. M. (1990). *Groundwater*. New Delhi: Wiley Eastern Limited, 356p.

Raviprakash, S.L., Krishna Rao, G. (1989). The chemistry of Ground water Paravada area with regard to their suitability for domestic and Irrigation purposes. *Indian Journal of Geochemistry*, *4*(1), 39-54.

Richter, B.C., and Kreitler, C.W. (1993). *Geochemical techniques for identifying groundwater salinization*. Boca Raton, CA: CRC.

Richter, J.P. in the literary works of Leonardo da Vinci. (1988). Water chemistry. In C.W. Fetter (Ed.): *Applied hydrogeology* (p.325-366). New York: Macmillan.

Rizk, Z. S. (1998). Falajes of United Arab Emirates: Geological Settings and hydrogeological characteristics. *The Arabian Journal for Science and Engineering*, *23*(1C), 3–25.

Rizk, Z. S., Alsharhan, A. S. (1999). Application of natural isotopes for hydrogeologic investigations in United Arab Emirates. *Proceedings of the Fourth Gulf Water conference, Manama, Bahrain (1999)*, pp. 197–228.

Rizk, Z. S., & Alsharhan, A. S. (2003). Water resources in the UAE. *Developments in Water Science*, *50*, 245-264.

Rossi, C. (2000). Bruno de Finetti: the mathematician, the statistician, the economist, the forerunner'. In *The 21st Annual Meeting of the International Society for Clinical Biostatistics* (ISCB), Sept. 4-8, 2000, Trent, Italy.

Salman, S. A., Melogy, A. A., Shaban, A. M., & Hassaan, M. M. (2013). Hydrogeochemical characteristics and classification of groundwater in Sohag Governorate, Egypt. *Journal of Applied Science Research, 9*(1), 758-769.

Saskatchewan Government. (2008). *Total dissolved solids fact sheet for private water and health regulated public water supplies*. Saskatchewan Health, Regional Health Authorities, Saskatchewan Watershed Authority, Saskatchewan Agriculture, Agriculture and Agri-Food Canada– PFRA and Saskatchewan Environment.

Sherif, M., Mohamed, M., Kacimov, A., & Shetty, A. (2011). Assessment of groundwater quality in the northeastern coastal area of UAE as precursor for desalination. *Desalination*, *273* (2-3), 436-446.

Skougstad, M.W., and Horr, C.A. (1963). *Chemistry of strontium in natural water:* U.S. Geological Survey, Water-Supply Paper 1496

Statistical yearbook of Abu Dhabi. (2014). *Statistics Centre of Abu Dhabi*. From: http://www.scad.ae/ar/statistics/Pages/Statistics.aspx?ThemeID=7&TopicID=48&SubTopicID=15&PublicationID=539

Steinpress M. G. (2004). 3.1 Naturally occurring Cr (VI) in groundwater, including the Presidio in San Francisco case study, chapter 3: *Naturally occurring Cr(VI) in groundwater, Chromium(VI) Handbook*, pp. 89-137. CRC Press.

Sulin, U.A. (1948). Basics of classification of natural water. Moscow. U.S.S.R. (in Russian).

Thiros, S.A. (2010). *Conceptual understanding and groundwater quality of the basin-fill aquifer in the Santa Ana Basin, California*. In: Thiros, S.A., Bexfield, L.M., Anning, D.W., Huntington, J.M. (Ed.). U.S. geological survey professional paper, 1781, 219-265.

Thomas, R.J., Finlayson, A., Smith, R.A., Arkley, S.L.B. and Farrant, A.R. (2012). *Geology of the Sweihan and Remah 1: 100 000 Map Sheet, United Arab Emirates*. (Keyworth, Nottingham: British Geological Survey), and Ministry of Energy, United Arab Emirates, ISBN 9780852727171.

Todd, D.K. (1980). *Groundwater hydrology*: John Wiley and Sons, Icn., New York, USA, 535 p.

TSC Water Treatment Engineering Team. (2009). *Alkalinity fact sheet*. U.S. Department of the Interior Bureau of Reclamation. Retrieved October 11, 2014, from www.usbr.gov/pmts/water/.../08%20-%20Alkalinity.pdf

Tuna, A.L., Yilmaz, F., Demirak, A., Ozdemir, N. (2007). Sources and distribution of trace metals in the Saricay stream basin of Southwestern Turkey. *Environmental Monitoring and Assessment, 125*, 47-57.

US EPA. (1991). *Inorganic nitrate/nitrite (sodium and potassium nitrates)*. R.E.D facts. Pesticides and toxic substances (7508W).

USGS. US Geological Survey. (1996). *Groundwater resources of Abu Dhabi Emirate*.

US Salinity Laboratory Staff (1954). *Diagenesis and improvement of saline and alkali soils* (p.60-160), (Agricultural Handbook; 60). Washington, DC: US Department of Agriculture.

Weil, R. R., Weismiller, R. A., & Turner, R. S. (1990). Nitrate contamination of groundwater under irrigated coastal plain soils. *Journal of Environmental Quality*, *19*(3), 441-448.

WHO. World Health Organization. (1993).*Guidelines for drinking water quality*, 2nd Edition, vol. 1, 188 p.

WHO. (1996). Guidelines for drinking water quality. Second Edition, vol. 2. Health criteria and other supporting information. International programme on chemical safety. World Health Organization. Geneva.

WHO. (2003). pH in drinking water. Background document for development of WHO Guidelines for Drinking-water Quality. In *Guidelines for drinking-water quality*, Vol. 2. *Health criteria and other supporting information*. 2nd edition. World Health Organization, Geneva, 1996.

WHO. (2006). *WHO guidelines for drinking water quality*. First addendum to third edition. World Health Organization, Vol.1.

WHO. World Health Organization. (2011). *Guidelines for drinking water quality*. Fourth Edition. WHO Library Cataloguing –in-Publication Data. Geneva.

Wilcox, L.V. (1955). *Classification and use of irrigation waters*. USA, Washington. Salinity Lab, Circulation No. 969.

Yidana,S.M., Banoeng-Yakubo, B., Akabzaa, T.M. (2010). Analysis of groundwater quality using multivariate and spatial analyses in the Keta basin, Ghana. *Journal of African Earth Sciences, 58* (2), 220-234.

Zaporozec, A. (1972). Graphical interpretation of water quality data. *Groundwater, 10* (2), 32-43.

Zhang, Ming-Kui, Wang, Li-Ping, He, Zhen-Li. (2007). Spatial and temporal variation of nitrogen exported by runoff from sandy agricultural soils. *Journal of Environmental Sciences, 19,* 1086-1092.

Zhang, Y., Guo, F., Merg, W., Wang, X-Q. (2009). Water quality assessment and source identification of Daliao river basin using multivariate statistical methods. *Environmental Monitoring and Assessment, 152*, 105-121.