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Assessment of Groundwater Quality in the Al Khatim and Remah Area of the United Arab Emirates

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ASSESSMENT OF GROUNDWATER QUALITY IN THE AL KHATIM AND REMAH AREA OF THE UNITED ARAB EMIRATI

Qasim Raza Khan

This thesis is submitted in partial fulfilment of the requirements for the degree o
Master of Science in Water Resources

Under the Supervision of Dr. Dalal Matar Alshamsi

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Declaration of Original Work

I, Qasim Raza Khan, the undersigned, a graduate student at the United Arab Emirates University (UAEU), and the author of this thesis entitled "*Assessment of Groundwater Quality in the Al Khatim and Remah Area of the UAE*", hereby, solemnly declare that this thesis is my own original research work that has been done and prepared by me under the supervision of Dr. Dalal Matar Alshamsi, in the College of Science at UAEU. This work has not previously been presented or published or formed the basis for the award of any academic degree, diploma or a similar title at this or any other university. Any materials borrowed from other sources (whether published or unpublished) and relied upon or included in my thesis have been properly cited and acknowledged in accordance with appropriate academic conventions. I further declare that there is no potential conflict of interest with respect to the research, data collection, authorship, presentation and/or publication of this thesis.

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Abstract

Groundwater constitutes an important part of the available water resources in arid areas. Knowledge of the quantitative and qualitative status of groundwater is a key aspect in optimal groundwater management. The chemical characteristics of groundwater in two neighboring areas (Remah and Al Khatim) have been used to identify the processes controlling groundwater chemistry in the sand aquifer of Abu Dhabi Emirate, United Arab Emirates. Furthermore, the suitability of the groundwater for agricultural purposes was assessed using a range of indices. Both areas showed elevated levels of nitrate, potassium and cadmium, indicating the impact of agricultural activities. The groundwater was found to be unfit for agricultural purposes as explained by the agricultural indices. Radon causes lung cancer when inhaled or ingested in higher concentration. The radioactive study of Radon-222 showed its concentration below the WHO permissible guidelines. However, considering that groundwater is the only available water source for irrigation, it will continue to be used for agriculture. This study therefore provides valuable technical support for farmers, decision makers and other stakeholders to develop strategies for sustainable groundwater development in the context of food security.

Keywords: Groundwater**,** Salinity, major cations and anions**,** heavy metals**,** aquifer.

Title and Abstract (in Arabic)

تقدير جودة المياة الجوفية في منطقة الختم ورماح في دولة الإمارات العربية المتحدة

الملخص

تعد المياه الجوفية مصدرًا هامًا من الموارد المائية المتاحة في المناطق القاحلة. وبالتالي تعتبر معرفة الحالة الكمية والنوعية للمياه الجوفية أحد أهم الجوانب الرئيسية للإدارة المثلى للمياه الجوفية. في هذا البحث تمت دراسة الخصائص الكيميائية للمياه الجوفية في منطقتين متجاورتين (الرماح والختم) لتحديد العمليات التي تتحكم في كيمياء المياه الجوفية في طبقة المياه الجوفية الرملية لإمارة أبو ظبي في دولة الإمارات العربية المتحدة. إضافة إلى ذلك، تم تقييم مدى ملاءمة المياه الجوفية للأغراض الزراعية باستخدام مجموعة مختلفة من المؤشرات .و أظهرت نتائج الدراسة أن المنطقتين كليهما تحتويان على مستويات مرتفعة من النيترات والبوتاسيوم والكادميوم ، مما يشير إلى تأثير الأنشطة الزراعية (تسرب المواد من الأسمدة للمياه الجوفية). و وجد أن المياه الجوفية غير صالحة للأغراض الزراعية كما هو موضح في المؤشرات الزراعية. كما أظهرت الدراسة الإشعاعية للرادون-222 أن تركيزه أقل من إرشادات منظمة الصحة العالمية المسموح بها. وقد تمت دراسة الرادون تحديداً لكونه مسبباً لسرطان الرئة عند استنشاقه أو ابتلاعه بتركيز أعلى من الحد المسموح به. ونظراً إلى أن المياه الجوفية هي مصدر المياه الوحيد المتاح للري في منطقتي الدراسة ، فسوف يستمر استخدامها للزراعة. ولكن هذه الدراسة قد تحسن من أساليب الاستخدام، حيث أنها توفر دعماً تقنياً قيماً للمزارعين وصانعي القرار وغيرهم من أصحاب المصلحة لوضع استراتيجيات و خطط تطويرية لأفضل وأمثل استخدام للمياه الجوفية وبطريقة مستدامة ضمن إطار استدامة المياه والأمن الغذائي.

مفاهيم البحث الرئيسية: المياه الجوفية، الملوحة، الأيونات والكاتيونات الأساسية، المعادن الثقيلة، مستودع للمياه الجوفية.

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Praises for Almighty Allah, the creator of this Universe, Who guides us in the oceans of darkness and enables us to overcome the difficulties in comical situations. All respect for Prophet Muhammad (Peace and Blessings Be Upon Him), Who enabled us to recognize our Creator and to understand the philosophy of life.

I express my cordial gratitude to my supervisor Dr. Dalal Matar Alshamsi for her encouraging attitude and constructive suggestions. I'm very thankful for her supervision and help in the critical time of my studies.

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Dedication

To my beloved mother who always prays for my success and prosperity, and my gracious father the source of strength and inspiration.

A special feeling of gratitude to my friends and family members who have supported me throughout the process.

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List of Abbreviations

°C	Degree celsius
µS/cm	Micro siemens per centimetre
ADSSC	Abu Dhabi Sewage Services Company
AK	Al Khatim study area
BGL	Below ground level
Bq/L	Becquerel per litre
EAD	Environment Agency of Abu Dhabi
GW	Groundwater
Km^2	Square kilometre
mEq/L	Milliequivalent per litre
mg/L	Milligram per litre
mm	Millimetre
Mm^3	Million cubic meters
mS/cm	Milli Siemens per centimetre
pH	Hydrogen ion concentration
R or RMH	Remah study area
UAE	United Arab Emirates

Chapter 1: Introduction

1.1 Overview

The Arabian Peninsula which covers an area of almost 3.11 million square kilometers, is one of the driest regions in the world. The United Arab Emirates is located in the Arabian Peninsula. The largest emirate of the United Arab Emirates is the Emirate of Abu Dhabi which has an area of 67,340 km^2 and occupy 87% of the UAE (Figure 1). It is located at the west and south-west of the UAE at 24° 28' 0" N, 54° 21' 59.9" E. The Arabian Gulf is at the north of Abu Dhabi, Saudi Arabia at the south and west and Sultanate of Oman to the east.

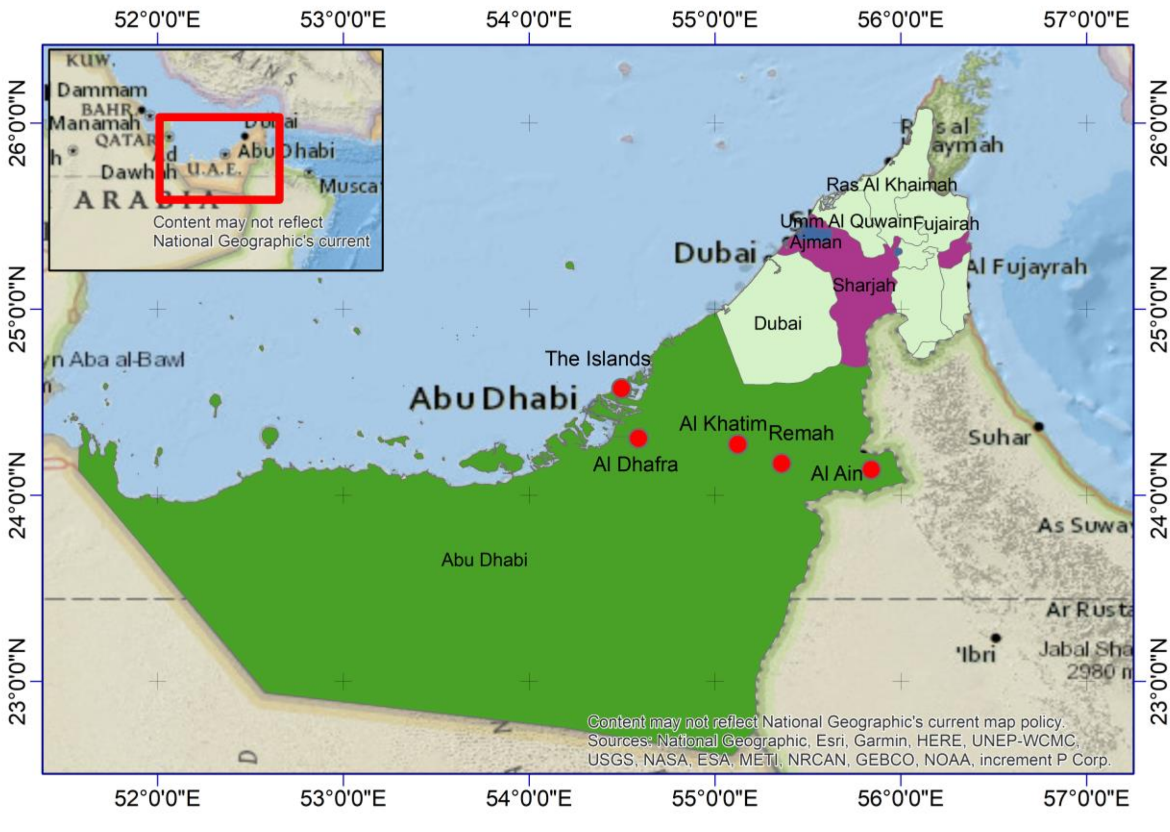

Figure 1: Map of the UAE showing Emirate of Abu Dhabi in green

The emirate of Abu Dhabi is divided geologically into four regions named as Island of Abu Dhabi, Western Region, Eastern Region, and Gulf Islands. The Emirate is dominated with the sand dunes that almost reach 300 meters above the sea level at some areas.

1.2 Climate of Abu Dhabi

Abu Dhabi is in the tropical dry region, where the tropic of Cancer runs through the south of the Emirates. It is because of this reason that the climate is arid which is characterized by the high temperature throughout the year (Sheppard, 1993).

The temperature in the summer is very high which results in high relative humidity. The temperature is lower in the winter but overall it is characterized as warm winter. The Winter season ranging from December to March is affected by the Siberian High Pressure that results in Shamal winds in North and Heavy fogs late night. The highest air temperature recorded in 2016 was in the month of June, July and August (Figure 2). The average minimum temperature in Abu Dhabi in 2016 was 22.6 °C whereas the recorded average maximum temperature was 34.7 °C (SYB, 2017).

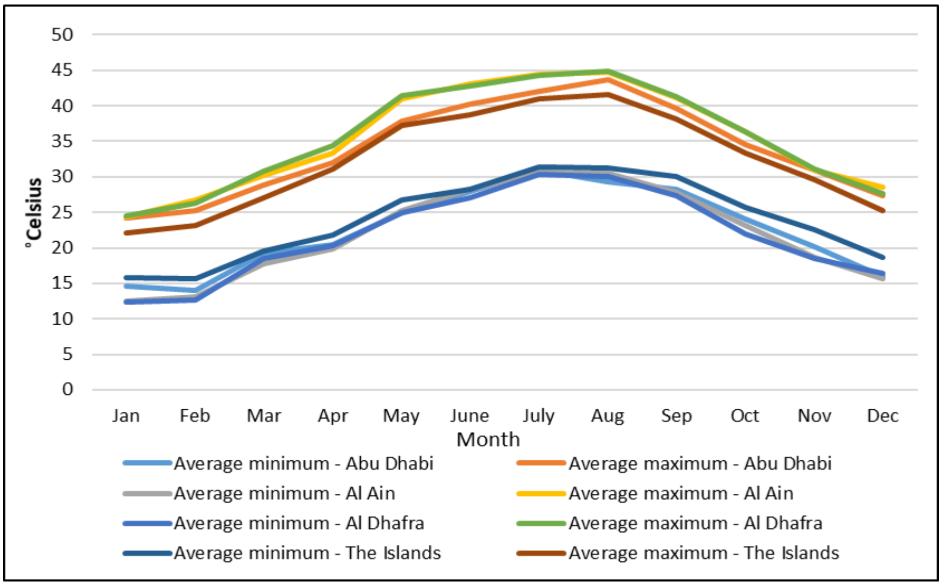

Figure 2: Average monthly air temperature for the year 2016 (SYB, 2017)

The degree of precipitation is scant, in addition the total precipitation varies from year to year. The tropical cyclone extending from Indian Ocean to Arabian Gulf and the Shamal winds results in the rain, and fog. These Shamal winds are the reason for spring and winter rainfall from the month of December to April (Glennie and Singhvi, 2002). The average annual rainfall in 2015 was 87.4 mm and it has decreased to 60.7 mm in 2016 (Figure 3) (SYB, 2017).

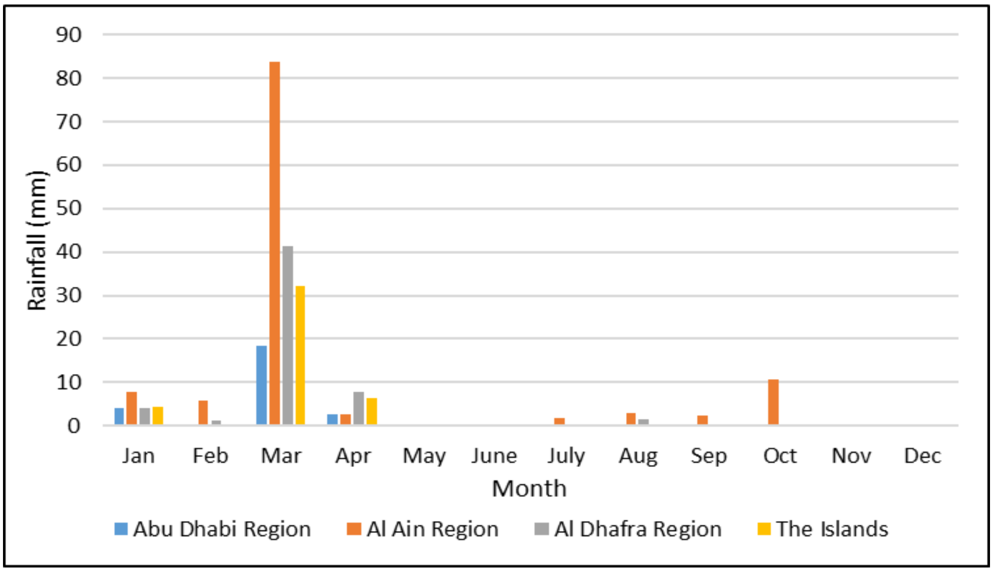

Figure 3: Average monthly rainfall for the year 2016 (SYB, 2017)

In the year 2016, the Eastern Region of Abu Dhabi has the highest precipitation that was recorded (Figure 4) on the 8th of March (data from Global Precipitation Measurement).

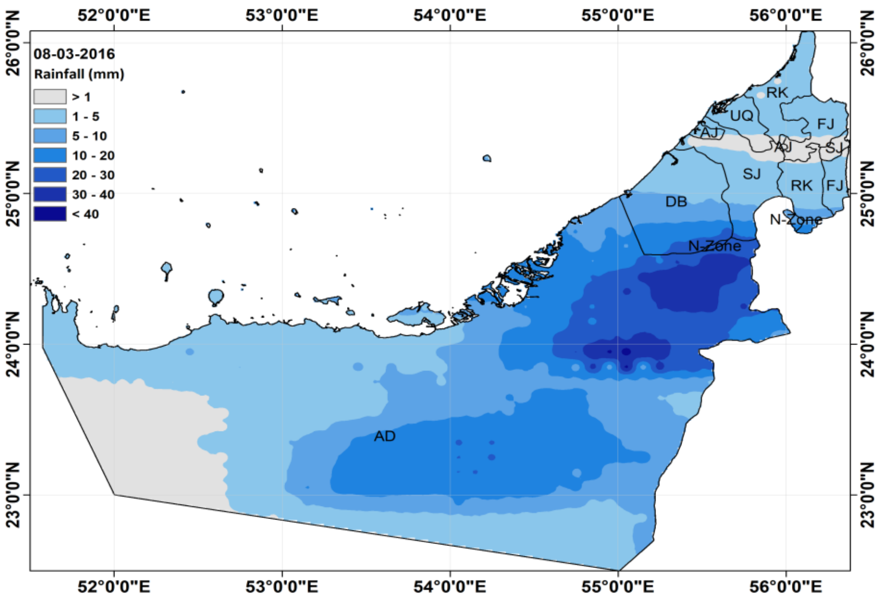

Figure 4: Highest rainfall event in UAE on Mar 8, 2016

1.3 Water Resources in UAE

The UAE as a whole and Abu Dhabi in particular relies on conventional as well as non-conventional water resources. With the increase of population and economic growth, the need for water is increasing. The conventional water resources include seasonal floods, falajes, springs, and the groundwater. On the other hand, the non-conventional water resources include desalination of seawater and brackish water, and treated sewage water (Rizk and Alsharhan, 2003).

1.3.1 Conventional Water Resources

The conventional water resources include seasonal floods, falajes, springs, and the groundwater. The UAE does not have any perennial surface water resources. The seasonal floods accounts for 125 Mm^3/year, falaj discharges 20 Mm^3/year, permanent springs 3 Mm^3/year, and 109 Mm^3/year of aquifer recharge (Rizk and Alsharhan, 2003).

The seasonal flood mostly occurs in the eastern region, where rainfall is strong but short lasting. Since, the porosity and permeability of the igneous and metamorphic rocks are low, therefore large volume of rain water moves as a surface water from the mountainous area in the east (Al Ain) to west (Arabian Gulf).

Falajes are the historic water distribution system that were used in early times for agricultural activities. Most of the UAE falajes are dry at the present, due to excessive withdrawal of groundwater. Discharge from falajes varies depending on the location of the source wells, nature of the source aquifer, the annual rainfall, and seepage from the tunnel sides. Al Gheli is a type of falaj which carry water only in the winter and it directly depends on the rainfall. The water of Al Gheli falajes is renewable and therefore it has good quality. The most of UAE falajes belong to Al Gheli type (Rizk and Alsharhan, 2003).

A spring is the discharge or outcrop of groundwater at the ground surface. The spring at UAE is discharged from local and intermediate groundwater flow systems (Rizk and ElEtr, 1997). Several springs originate in the UAE, such as Khatt in Ras Al Khaimah, Maddab in Al Fujairah, and Ain Al Faydah in Al Ain. These springs are utilized as recreational and touristic sites. Ain Al Faydah spring originates from Miocene gypsum and clay layers through a thin loose Quaternary sediment, it is about 4 km west of Hafeet Mountain and located at the south of Al Ain town (Rizk and Alsharhan, 2003).

Groundwater is an important part of the total water resource in arid and semi-arid regions (Keesari et al., 2014; Tsujimura et al., 2007). In the United Arab Emirates (UAE), located in the south-eastern part of the Arabian Peninsula, groundwater is the main source for irrigation of agricultural areas, as the climate is arid with no reliable surface water resources. Despite the scarcity of water, water demand in the UAE has increased tremendously over the last decade. The rapid population growth, industrial development, and booming economy have increased water demand in various sectors. Thus, the sustainable use of groundwater in light of the increasing demand, has become a serious challenge. The over-exploitation of groundwater resources has already caused severe impacts such as salinization of groundwater, desertification, and degeneration of vegetation (Lapworth et al., 2013).

The sustainable management of water resources depends upon the comprehensive understanding of the hydrogeological systems, their behavior as well as their evolution processes (Brkić et al., 2016; Eissa et al., 2014; Sophocleous, 2010). Groundwater quality reflects the combined effects of many hydro-chemical processes such as weathering, dissolution, ion exchange and various biological processes along the groundwater flow path (Jeevanandam et al., 2007). Therefore, hydrochemical analysis is commonly carried out to study the characteristics of the aquifer, salinity problems, and recharge of the aquifer (Jianhua et al., 2009; Zhu et al., 2007). Furthermore, the hydrochemical analysis can also be used to identify the interaction of water with minerals of rocks and sediments that can thus provide insights into aquifer heterogeneity and connectivity as well as into the physical and chemical processes controlling water quality (Jasechko, 2016; Wells and Price, 2015).

The processes affecting the groundwater composition vary in different areas along the sub-surface flow path of water. The process of dissolution typically occurs in the recharge area, ions exchange phenomena occur during the flow whereas evaporation, precipitation and ion exchange dominate the discharge area in controlling groundwater chemistry (Adams et al., 2001; Tóth, 1999).

1.3.2 Non-conventional Water Resources

Due to the limited conventional water resources in the UAE, the country has worked on non-conventional water resources to meet the increasing demand. The non-conventional water resources in the UAE include the desalination of seawater and the brackish groundwater, and the treated wastewater.

According to (ESCWA, 2009), UAE is the second largest country globally in terms of installed desalination capacity. UAE shares 14% of the total installed desalination capacity globally with a capacity of 8,743,000 m^3/day. Most of these plants are located at the coastline of Arabian Gulf and Gulf of Oman. The largest desalination plants in the Abu Dhabi emirates are Um Al Nar, Mirfa, and Taweela (McDonnell, 2014).

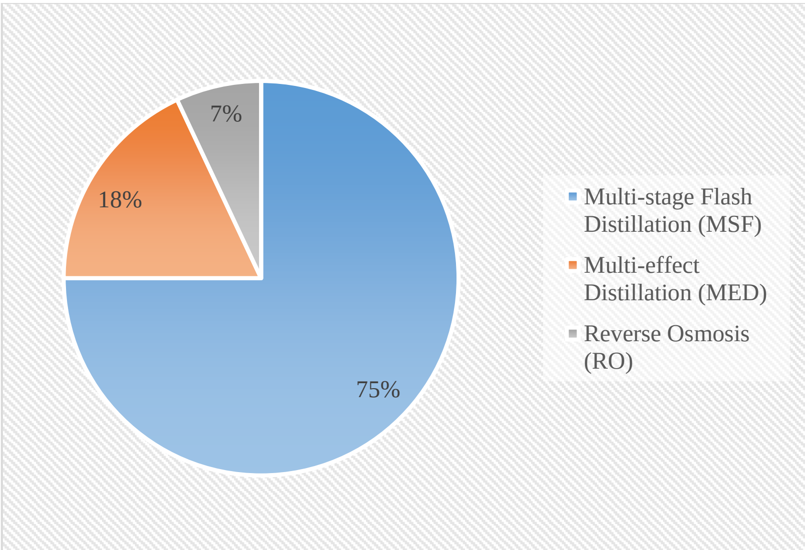

Figure 5: Desalination technology by type in UAE

There are different desalination processes, mainly including thermal desalination (MSF and MED) and RO membrane separation. In UAE, the MSF technology shares 75% of its desalination capacity (Figure 5). These MSF desalination plants are coupled with power plants and the fuel used mostly are the natural gas (Assaf and Nour, 2015).

The UAE also depends on other sources of water such as the treated wastewater. This idea was introduced in UAE in 1980s to meet some of the demands (Al-Zubari, 2008). With the growing economic activities and increasing population, the amount of treated wastewater is also increasing. The treated wastewater has increased in 2013 to 283 Mm^3 (Million cubic metres).

The Abu Dhabi city produces highest with 74% of the treated wastewater and the Western Region produces the lowest 5% of the total treated wastewater (Mohamed, 2014). The use of this wastewater includes the irrigating parks, roadside soft-scapes and the golf courses.

Chapter 2: Geology and Hydrogeology

The topographic surface of Al Ain area shows a high elevation surface containing a westerly directed trough axis (Elmahdy and Mohamed, 2015). The porosity and permeability of the karst limestone, marly limestone, and the marl layers are low. Large volume of rainwater flow as surface runoff. The flow mostly occurs from the eastern region (Al Ain) and towards the desert in the west (study area) (Elmahdy and Mohamed, 2015). The extension of wadi courses to the western part, towards the study area, is dominated by dune fields with most of the study area covered by Quaternary deposits. The Quaternary deposits recognized here are of four types that include fluvial deposits, desert plain deposits, sabkha deposits and aeolian sand (Hamdan and Anan, 1993; Hamdan and Bahr, 1992). The study area, having sand dunes, is identified as no-recharge area with all the precipitation captured by the sand dunes and later evaporated (Imes and Wood, 2007).

The major geological feature in Al Ain area is the Hafeet Mountain. The Mountain is composed of carbonate and evaporitic rocks such as limestone, dolomite, and gypsum. The geological process of deformation and karstification has destroyed the porosity of the shallow aquifer. The geology of Hafeet Mountain has a significant impact on the hydrology of the surrounding areas (Hamdan and Bahr, 1992). The gravel plain consisting of gently inclined gravel and sandplain is built up of the down-wash material drained by wadis from the eastern Mountains of Oman.

2.1 Hydrogeological Units

There are four identified hydrogeological units in the Emirate of Abu Dhabi (Embabi et al., 1993), as shown in figure 6: (1) The Carbonate aquifer in the North and East (Hafeet Mountain), (2) the sand dune aquifer (linear and star sand) in the south and west, (3) the western gravel aquifer in the east, and (4) the coastal aquifer in the west along the coast of the Arabian Gulf.

2.1.1 The Limestone Aquifers

There are two limestone aquifers in United Arab Emirates, the northern limestone aquifer (Wadi Al Bih Aquifer) in Ras Al Khaimah area and Hafeet Mountain limestone aquifer in Al Ain.

The northern limestone aquifer is composed of fractured limestone and dolomite of Permian to Triassic age. The composition of aquifer rocks includes stratified, hard, dense, and non-porous at the surface with extensive internal karstification. The aquifer is recharged from a catchment of 475 km^2, with an average elevation of 1,050 m above sea level (Abu Al Enien, 1996).

The composition of Hafeet Mountain includes 1,500 m thick sequence of interbedded limestone and marl with gypsum and dolomite. The formation was formed during the Lower Eocene to Miocene age. The aquifer in the Hafeet Mountain area is composed of limestone of the Middle Eocene Dammam Formation. The porosity is almost nil except for infrequent unfilled fractures, vugs and heterogeneous secondary porosity (Whittle and Alsharhan, 1994). Previous study by (Khalifa, 1997) indicates that the aquifer is deep and composed of brackish water.

Since, the salinity of the water from this aquifer produced exceeds the maximum level for drinking water, it is not suitable for human consumption. An inspection in a well near Hafeet Mountain shows that most of the rocks consist of massive limestone and marl having very low porosity. An interval between 101 and 112 metres shows a fractured limestone.

Fracture width observed was 9 cm, which shows that most of the water yielded are because of this fracture (Khalifa, 1997).

2.1.2 Gravel Aquifers

The piedmont plains having alluvial deposits hold the largest reserve of fresh groundwater in the UAE. Two aquifers are identified, eastern gravel aquifer and western gravel aquifer. The eastern gravel aquifer is composed of alluvial flats filling the embayment between promontories of rock spurs extending into the Gulf of Oman.

The eastern gravel aquifer comprises rock and coarse gravel. The aquifer is mainly fresh groundwater that drain from the wadi fans towards the sea. The low chloride concentrations in this aquifer suggest younger water, in hydrogeological terms. Previous study by (Yurtsever, 1992) indicates that this region partially receives recharge form the two air masses, winter precipitation from the Mediterranean Sea and Monsoon rains from Indian Ocean. An exceptional wet year of 1972 is identified as the recharge of this aquifer, where the recent study also indicated the aquifer is receiving modern recharge.

The western gravel aquifer (study area) is composed of 60 m sequence of sand and gravel with thin interbeds of silt and clay. The alluvium was derived from the ophiolitic Oman Mountains. The wadis around the Al Ain is located between NE-SW trending sand dunes. Recharge of western gravel aquifer comes from rain, that falls on the western flank of the Northern Oman Mountains. Investigation of the aquifer using oil exploration up-hole seismic data indicates paleodrainage network, that contain saturated alluvial fill (Woodward and Menges, 1991). Analysis of the groundwater sample indicates meteoric water.

The water is enriched with high chloride content, shows the high residence time of water in the surface depression before recharge. The high chloride content confirms that the dissolution of salts during its flow to the aquifer. Evaporation from the groundwater also increases the salinity in the reservoir, since the region is arid.

The possibility of mixing rainwater, while percolating downwards through fractures, with the old water was also discussed by (Rizk and Alsharhan, 1999). The dissolution of salts while movement of water from the east to the west gravel aquifer is also the main reason of high salinity in water.

2.1.3 Sand Dune Aquifer

The study area falls in the sand dune aquifer. The sand dune aquifer covers about 74% of the total area in the United Arab Emirates and yet it is the least studied aquifer in the UAE (Figure 6). The sand dune aquifer can be categorized into two types based on the dune shapes. The first type is the linear dunes which receive water from Hafeet Mountain and the western gravel aquifer located in the north-east of Abu Dhabi emirate. The second type is barchan-like shaped and it is located in the southern part of Abu Dhabi which is stretched between Liwa and Madinat Zayed, receiving water from Oman and Saudi Arabia (Elmahdy and Mohamed, 2015).

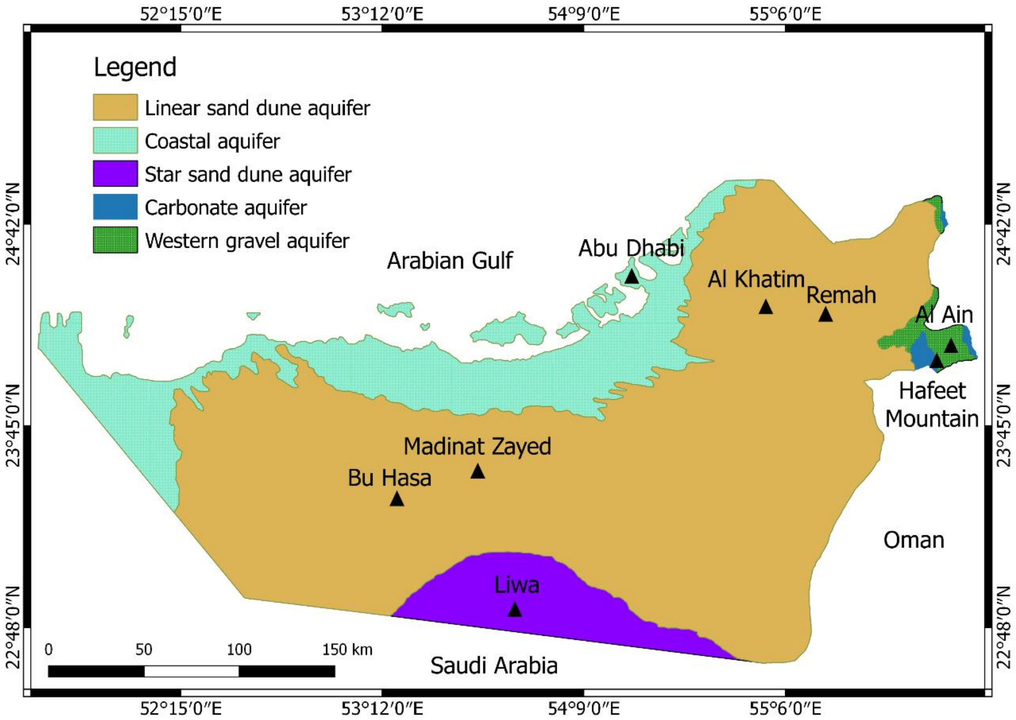

Figure 6: Map of the Abu Dhabi groundwater aquifers (modified to study area after (Elmahdy and Mohamed, 2015))

The elevation of the sand dune aquifer gradually increases from the sea level at the Arabian Gulf until it reaches 250 meters above ground level in the south-central part at the Liwa Al Batin basin. There are pockets of fresh water in the Quaternary sand dunes between Madinat Zayed and Liwa. Investigation at Bu Hasa oil field indicates the presence of similar freshwater deposits (Rizk and Alsharhan, 2003). This aquifer shows high spatial variability in chemical properties of groundwater which may be influenced by the climate, aquifer geological characteristics, and the water table depth (Rizk and Alsharhan, 2003).

The groundwater formations in the UAE is broadly classified into two categories (Elmahdy and Mohamed, 2015). The upper unit which consists of the Quaternary unconsolidated clastic sediments which are found in the desert or sand aquifer throughout UAE and the lower unit which is composed of loosely cemented, calcareous sandstones, sandy limestone, gypsum, and silty chalk.

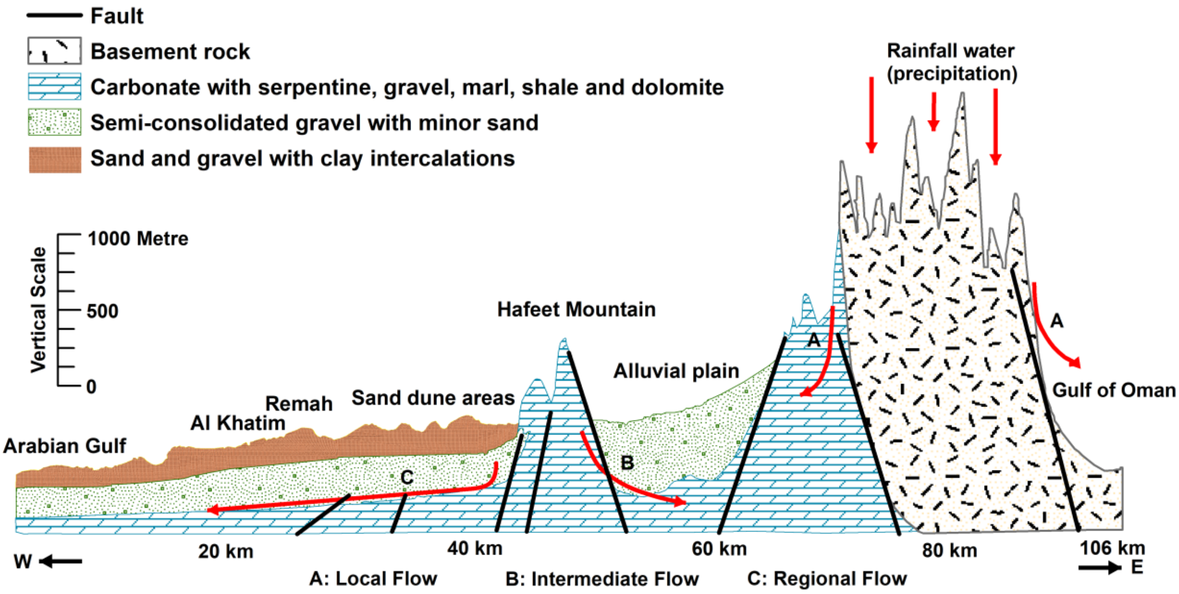

Figure 7: Lithological formation of groundwater-bearing rocks (A), topographic profile across the Abu Dhabi Emirate (B), profile showing the groundwater flow path from East to West (C) (modified for study area after (Elmahdy and Mohamed, 2015))

The groundwater is recharged because of precipitation in the eastern region at the Northern Oman Mountains and Hafeet Mountain. The lithological map (Figure 7) shows that the water moves under the ground from the east (Hafeet Mountain) passing through the study area and flowing towards the west (Arabian Gulf).

2.2 Study Area

The study areas Al Khatim and Remah lie in the east of the UAE between Abu Dhabi and Al Ain as shown in figure 8. The Emirate is characterized with an arid climate having an average rainfall of less than 100 mm/year and a very high rate of potential evaporation (2-3 m/year) (Iqbal et al., 2018).

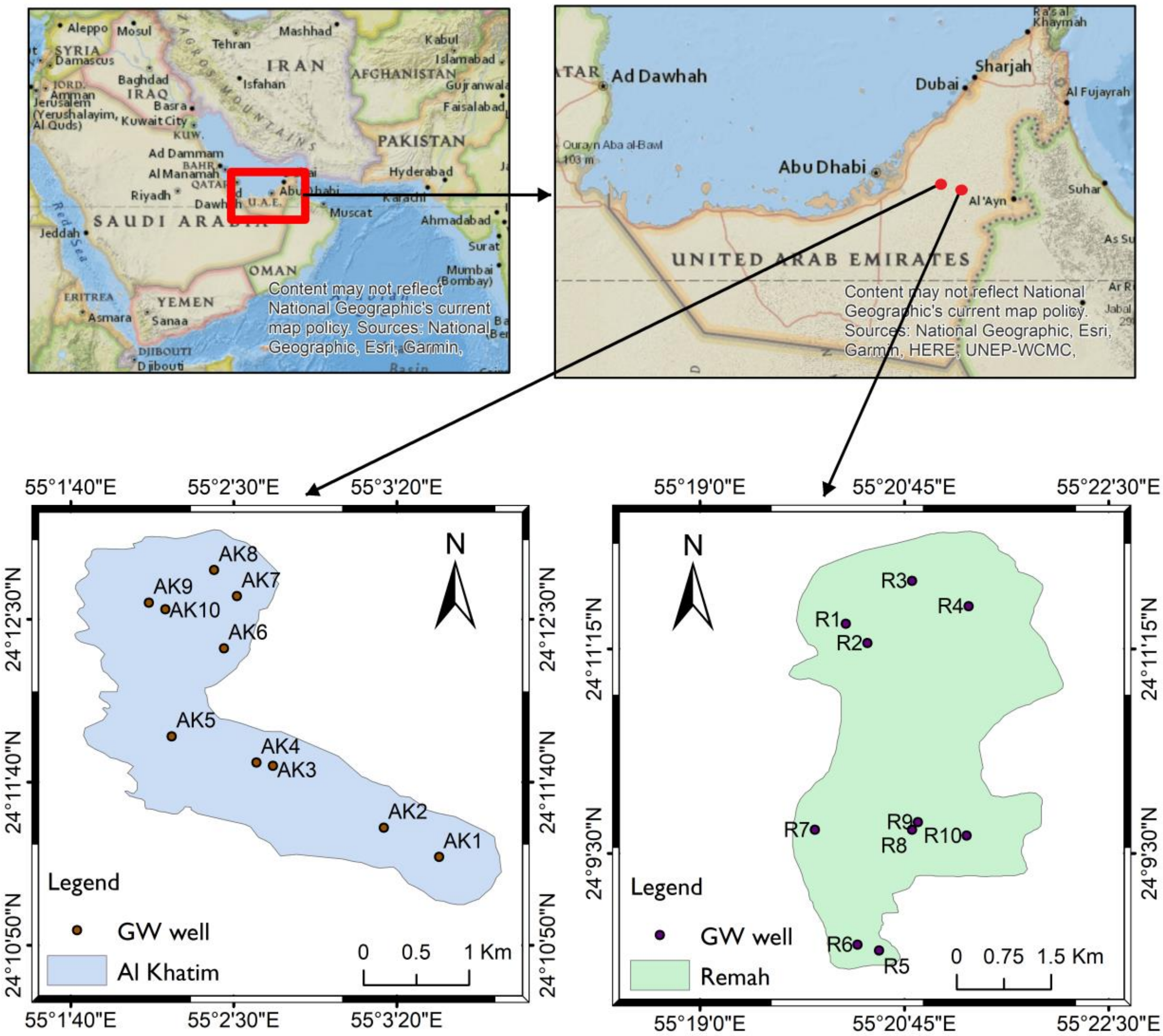

Figure 8: Al Khatim and Remah Study Areas

The geomorphology of Al Khatim and Remah area includes sand dune ridges, and inland sabkhas (Embabi et al., 1993). The city of Al Ain, in the proximity of the study area, is known as the largest oases of the Arabian Peninsula (El-Ghawaby and El-Sayed, 1997). The only perennial surface water resource is the spring at Ayn Al Fayda which is located about 15 kilometers south of Al Ain. The spring originates from Miocene gypsum and clay layers through thin Quaternary loose sediments (El-Shami, 1990). There are many farms and plantation forests in the study area (Abou El-Enin, 1993; Baghdady, 1998; Garamoon, 1996).

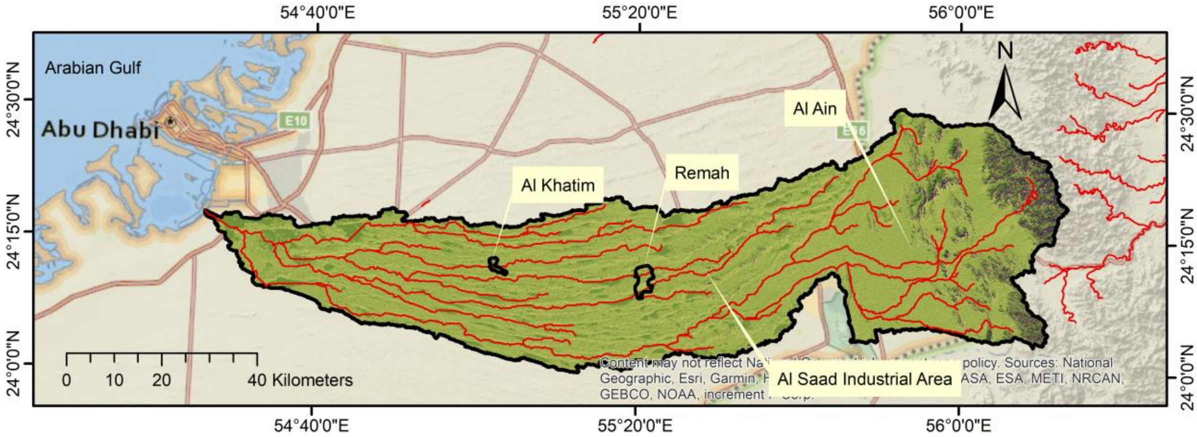

Figure 9: Catchment of the Study Area

The drainage basin was developed in ArcGIS 10.3 using ALOS 10m Digital Elevation Model. The catchment basin explains the surface flow of water. The water flow direction, as seen in (Figure 9) is from east to west. The Al Saad Industrial area also lies near to Remah. The water flow passes through Al Saad Industrial Area and towards Remah and Al Khatim.

The groundwater is mainly used for farming as well as for municipal irrigation. According to EAD (2016) there are total of 105,000 groundwater wells in the Emirate of Abu Dhabi. The major abstraction centers include Eastern Region with 80,000 wells, Western Region having 20,100 wells and some remote areas Ghayathi and Liwa South-West has 4,900 wells (Figure 10).

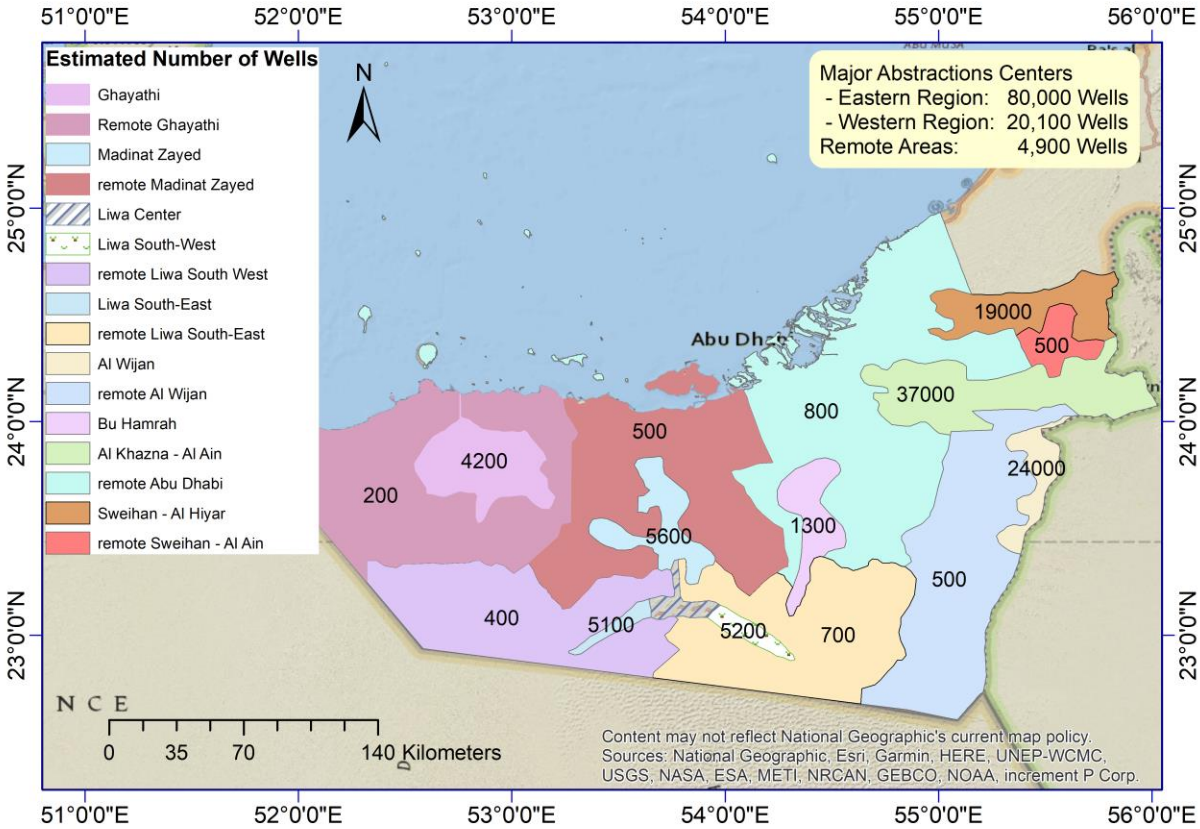

Figure 10: Groundwater Wells in Abu Dhabi Emirate (digitized (EAD, 2016))

The groundwater in the study area are mostly used for different purposes. In Al Khatim-Al Khaznah area the 74.14% of extracted groundwater is used for agricultural activities, 9.07% is used to irrigate forest and 16.79% is used by other categories which include amenity, household, industrial, livestock, municipal etc. In Remah area, the maximum 95.08% is used for farms, 0.91% for forest irrigation and 4.91% for others category (Figure 11).

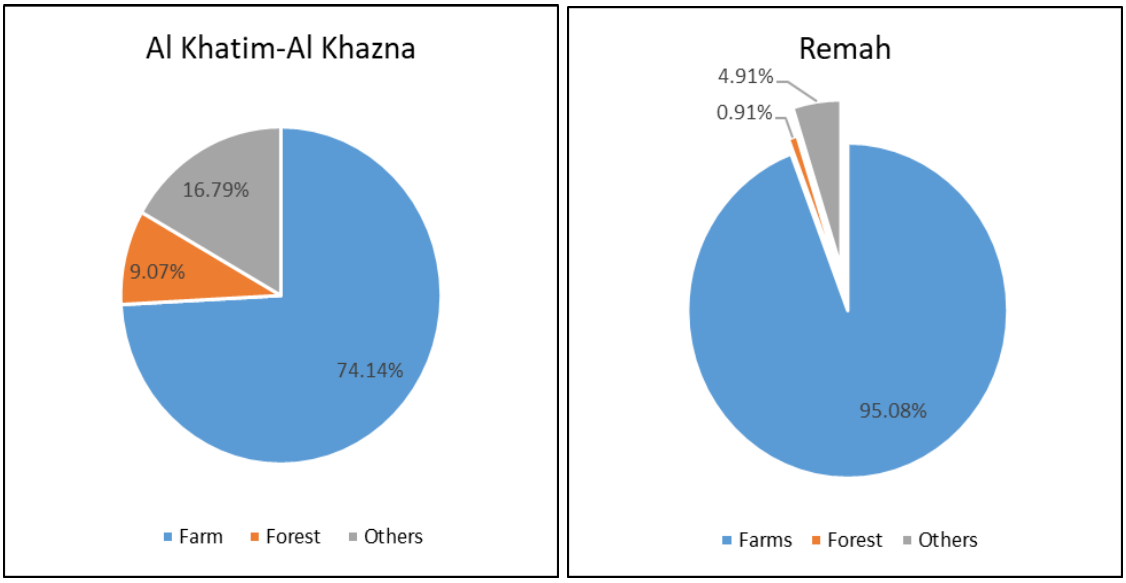

Figure 11: Groundwater usage percentage in study area (EAD, 2016)

Excessive withdrawal of groundwater and low recharge rate in the area has caused a significant decline of the groundwater levels and an increase of salinity. Due to the extensive agricultural activities in the region, the application of chemical fertilizers and pesticides is contaminating the groundwater and affecting the groundwater quality (Murad et al., 2012). Increased groundwater salinity and the rapid decrease in the water table is of significant concern for the sustainable management of the groundwater resources in the area.

2.2.1 Water Table Depth

The groundwater level is deep at Remah i.e., 155.5 m below ground level and the hydraulic head is 86.5 m above sea level. At Al Khatim, the recorded groundwater level is 32.6 m below ground level and the calculated hydraulic head is 73 m above sea level. The hydraulic head continues to decrease when moved towards the west (Arabian Gulf).

2.3 Statement of the Research

In the Emirate of Abu Dhabi, only few hydrochemical studies of groundwater have been conducted to date, including the area of Liwa (Al-Katheeri et al., 2009; Iqbal et al., 2018), the western coast (Mohamed, 2006; Sanford and Wood, 2001), and the eastern region (Mohamed and Hassane, 2016; Murad et al., 2012). The isotope study in the groundwater have been conducted in the Ras Al Khaimah, near Gulf of Oman (Murad, 2010), and in the eastern region (Alshamsi et al., 2013; Murad, 2010). The shallow sand dune aquifer of Abu Dhabi has been the subject of a study by Imes and Wood (2007), who suggested that the increase of solute observed in the groundwater is a result of the upward transport of solute from underlying mudstone and evaporate, and the loss of groundwater through evaporation. Elmahdy and Mohamed (2015) identified groundwater potential zones through resistivity surveys as well as from remote sensing data for the sand dune aquifer of Abu Dhabi. However, there are still considerable knowledge gaps in many parts of the emirate including areas where groundwater is extensively used for irrigated agriculture.

This study focusses on two neighboring agricultural areas, Remah and Al Khatim, which are located in the mid-eastern region of Abu Dhabi Emirate. The agricultural farms in Al Khatim produce dates, whereas in Remah, greenhouses are used for growing vegetables for commercial production. Large variations in salinity have been observed between these two areas, and despite the extensive use of groundwater for irrigation, little is known about the hydrochemistry of the groundwater. There is also an industrial area located upstream of Remah and Al Khatim. To date, little attention has been given to the problem of groundwater salinity in the area or to a potential effect of the industrial activities on the groundwater quality.

2.3.1 Objective

Hydrochemical and isotopic assessment of the groundwater was undertaken to provide technical support for farmers, decision makers and other stakeholders working towards sustainable groundwater development. The objectives of this study were to (1) assess the groundwater chemistry of the sand aquifer in the study area considering natural conditions (geological, hydrogeological, and climatic influences) and man-made (agricultural) influences, and (2) to evaluate the suitability of the groundwater for agricultural purposes. Two types of approaches are used to achieve the objectives, these are (1) the development of geospatial water quality maps, and (2) the examination of the suitability of the groundwater for irrigation purposes based on sodium percentage (Na%), sodium adsorption ratio (SAR), magnesium hazard (MH), and Kelly's index (KI).

Chapter 3: Materials and Methods

3.1 Sample Collection and Analysis

A comprehensive field survey was conducted, in the month of May 2017, in both study areas (Remah and Al Khatim) (Figure 12). The data collected through survey forms are available in appendix A. To study the hydrochemical composition, ten bore wells were randomly selected in each area and the farmers were interviewed to collect information regarding the condition and the purpose of usage. The groundwater level was measured prior to sampling at each well. Twenty groundwater samples (10 samples from each study area) were collected. The water samples collected from the wells were transferred into polyethylene bottles having nitric acid (HNO_3) for preservation and stored in an ice box. Electrical conductivity, salinity, and pH were determined in the field during sampling using U-52, Horiba, multi-parameter probe. The concentration of major cations and anions (Na+, K+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4, HCO_3^-, and NO_3^-) and trace metals (Cd, Cr, Zn, and Pb) were estimated in Laboratory following APHA (2005) standards.

The selection of cations and anions to be analysed were based on the conditions of the study area and the usage of these groundwater wells. Sodium, chloride, and calcium were selected as they are helpful in the identification of the source of salinity in the groundwater. Magnesium and potassium ions can be helpful in exploring and understanding the sand dune aquifer with types of rocks that are playing a role in determining the groundwater chemistry. The study area is located within an agricultural region and thus usage of fertilizer is likely. Furthermore, an industrial area is located upstream of the study area. Therefore, trace metals were included in the groundwater analysis as they can be helpful in determining the effect of anthropogenic activities (agricultural and industrial) on the groundwater chemistry.

Particularly cadmium can be an indicator of fertilizer use and was therefore included in the analysis.

Radon activity concentration was measured in groundwater samples collected from nine groundwater wells in Remah, and twenty-three groundwater wells in Al Khatim and Al Khaznah, using Rad7 -an electronic portable radon detector (from Durridge Co., USA). The water samples were collected directly from the well pump after switching on the pump for 20 minutes. The water samples were put in 40 mL vial and analyzed immediately by connected the vial by Rad7 H2O accessory. The Rad7 was settled in the car bag with air conditioning to avoid humidity effects, because the surrounding atmosphere humidity shall be less than 10% during the measurement. The measurements were performed in four cycles as well as one cycle for purging then the average value of Radon concertation was taken for the four cycles in Bq/m^3 which converted into Bq/L to be compared with WHO standards. furthermore, some corrections were done based on the period between the time of sampling and actual measurements.

The groundwater contains certain amount of natural radioactivity. It is because of the decay from uranium and different isotopes. For the purpose of this study, ^{222}Rn has been selected to calculate its concentration in the collected groundwater samples. The knowledge of its concentration, and source is important for the environment safety, and the sustainability of groundwater resources specially in the area of agricultural lands.

Figure 12: Field images of data collection

Statistical analysis, data categorization, development of water quality maps, and water quality analysis were carried out using Minitab 17, Microsoft Excel 2017, Arc GIS 10.3, and Aquachem (2014.2) water quality software, respectively.

3.2 Development of Water Quality Maps

The maps of different water quality parameters were developed in Arc GIS 10.3 based on field analyzed data. The geo-statistical analysis was used to create the quality maps for different parameters of the collected groundwater samples for Al Khatim and Remah area. Base maps of study area boundary were prepared using ground values. The detailed maps of all parameters were created using data interpolation techniques (Inverse Distance Weighted). There are many categories of interpolation techniques which can be used for prediction of water quality maps. In this study, the Inverse Distance Weight (IDW) method of interpolation was used for the delineation of detailed maps and management zones of water properties. The IDW is an interpolation technique which calculates the parameter values at un-sampled points using linear combination of observed points weighted by an inverse function of the distance from the point of interest to the observed points. The basic assumptions of this phenomena is that ground values near to un-samples points are match with each other than those faraway in their values (Li and Heap, 2008). It can be used when set of points is dense enough to capture the extent of local surface variation needed for analysis. The weight assigned is functional value of the distance of an input point from the output cell location. Larger the distance, the less impact the cell has on the output value. The mathematical expression of IDW equation-1 is given below:

$$Z(X_o) = \frac{\sum_{i=1}^{n} z(X_i) \times d_{i0}^{-r}}{\sum_{i=1}^{n} d_{i0}^{-r}} \quad \mathbf{(1)}$$

Where X_0 is the prediction function of neighbouring observations, Z (X_i), i = 1, 2, n, r is value of exponent that estimates the weight assigned to each observation, d is distance between known and unknown points. As the distance between these two points increases the weight decreases (Hengl, 2009).

3.3 Sustainability of Groundwater for Agricultural Use

The suitability of groundwater for irrigation depends upon its mineral constituents and thus can influence both the soil and the plants (Iqbal et al., 2018). To assess the quality of groundwater for agricultural purpose, different criteria were used such as; sodium percentage (Na%), sodium adsorption ratio (SAR), salinity hazards (EC), magnesium hazards, and Kelly's index (KI). All the concentrations for these criteria are in units of milliequivalents per litre (mEq/L).

Sodium adsorption ratio (SAR) (Richards, 1954) is used to determine the suitability of groundwater for agricultural purposes. The SAR indicates the degree of replacement of sodium ions with other ions that results in sodium hazard. The SAR can be expressed (Equation-2) as:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \quad (\mathbf{2})$$

Sodium percentage (Na%) (Wilcox, 1955) can be used to study the sodium hazards.. A low value of sodium percentage is good for irrigation, whereas a higher value indicates its unsuitability for irrigation. It can be expressed (Equation 3) as:

$$Na\% = \frac{Na^{+}+K^{+}}{Na^{+}+K^{+}+Ca^{2+}+Mg^{2+}} \times 100 \quad \mathbf{(3)}$$

Salinity Hazard (EC) is the presence of salt content in the irrigation water. Excess concentration of salt in the water and soil affects the crop yield and degrades the soil (Wilcox, 1955). The suitability of water for irrigation purpose was divided into four classes by Wilcox (1955), with an electrical conductivity greater than 3000 μS/cm in irrigation water is considered as unsuitable for irrigation use.

Magnesium Hazard (MH) measures the alkalinity of water and was expressed by (Raghunath, 1987) (Equation 4) as:

$$MH = \frac{Mg^{2+}}{(Ca^{2+}+Mg^{2+})} \times 100 \quad \mathbf{(4)}$$

The water associated with magnesium ratio exceeding 50 has higher alkalinity and thus it affects crop yield negatively (Iqbal et al., 2018). The water of magnesium hazard less than 50 is considered safe for irrigation.

Kelly’s Index (Kelley et al., 1940) measures the presence of sodium with respect to calcium and magnesium and can be expressed (Equation 5) as:

$$Kelly's\ Index\ (KI) = \frac{Na^{+}}{Ca^{2+} + Mg^{2+}} \quad \textbf{(5)}$$

Kelly’s index value greater than 1 indicates excess sodium in the water and is categorized as unsuitable for irrigational purposes, whereas a value less than 1 indicates the suitability of water for irrigation use.

Chapter 4: Results

The results of the hydrochemical analysis are shown in Table 1. Complete data is available in Appendix B. The coefficient of variation (CV) was used to describe the variability of groundwater properties, with CV $\leq$ 15% indicating low variability, 15% $<$ CV $\leq$ 35% indicating moderate variability, and CV $>$ 35% indicating high variability (Wilding, 1985).

As can be seen from Table 1, there is a moderate to high variability in most parameters. In the absence of any local guidelines, the different groundwater parameters were compared with the WHO standard guideline values (if applicable) (WHO, 2004).

Geospatial quality maps were developed for EC, salinity, pH, Na, Ca, Mg, K, Cl, SO_4, HCO_3, and NO_3. The results for the individual parameters are discussed below in more detail.

Table 1: Descriptive statistics of chemical concentration and water depth in groundwater in Remah and Al Khatim (CV: coefficient of variation).

Remah					
Parameters	**Min**	**Max**	**Mean**	**CV**	**(WHO, 2004)**
EC (mS/cm)	4.7	8	6.2	17.9%	0.78 – 31.2
Salinity (mg/L)	2,500	4,400	3,350	19.6%	-
TDS (mg/L)	3,155.7	5,380.1	4,147.9	17.9%	500 – 1500
pH	4.5	7.2	5.9	15.1%	6.5 - 8.5
Na (mg/L)	580.8	872.8	694.9	13.6%	200
Cl (mg/L)	850.5	1,473.5	1,115.5	18.9%	200 - 600
Ca (mg/L)	61.8	242	136.9	44.6%	75 - 200
Mg (mg/L)	20.5	47.3	29.2	29.2%	30 - 150
K (mg/L)	6.2	26.6	15	41.7%	10
SO4	1,142.5	2,015.95	1,512.6	19.6%	200 - 400
HCO3	32.1	50.6	39.3	15.3%	300
NO3	20.78	164.43	96.4	60.2%	45
Water Depth	102.5	198	155.5	19.9%	-
Al Khatim					
EC (mS/cm)	16.7	24.2	19.84	11.5%	0.78 – 31.2
Salinity (mg/L)	9700	14,600	11,770	12.6%	-
TDS (mg/L)	90,06.4	14,371.2	10,893.1	13.4%	500 – 1500
pH	5.02	7.03	6	9.6%	6.5 - 8.5
Na (mg/L)	2,046.8	2,864.5	2,452.6	10.7%	200
Cl (mg/L)	4,093.5	5,887.8	4,729.9	13.4%	200 - 600
Ca (mg/L)	436	1,007	683.8	21.7%	75 - 200
Mg (mg/L)	89	183	124.7	27.9%	30 - 150
K (mg/L)	12.4	48.4	27.4	44.6%	10
SO4	2,827	5,457	3,632	24.3%	200 - 400
HCO3	80	140	104.3	17.3%	300
NO3	14	1,060	315.7	95%	45
Water Depth	17.1	42.2	32.6	30.1%	-

All units are in mg/L, except water depth in meters and EC in mS/cm.

4.1 Physical Properties

The physical properties access and determine the acceptability of groundwater quality in the area. The physical parameters that were studied in the groundwater samples of study areas include Electrical conductivity, salinity, total dissolved solids and temperature. The explanation of these physical parameters for the study area is given below:

4.1.1 Electrical Conductivity and Salinity

Electrical conductivity (EC) is the measurement of the ionic concentration in water which allows the electric current to pass through at 25 °C. EC of the groundwater shows a rapid determination of total dissolved solids, it is an important parameter to demarcate salinity hazard. According to WHO (2004), the permissible EC in the groundwater ranges between 0.78 to 3.12 mS/cm. The mean value of EC of the samples in Remah is 6.2 mS/cm which is less as compared to the mean value in Al Khatim samples 19.84 mS/cm.

The electrical conductivity is the main factor to determine the suitability of water for drinking purpose. The study area, Remah and Al Khatim shows higher values of EC than the WHO (2004) permissible limit, that draws a conclusion that groundwater in both the areas are not suitable for drinking purposes. The value of EC is linked to the total dissolved solids (TDS), Harter (2003) reported that increase in the value of TDS increases the EC in water.

Salinity of groundwater also shows the same pattern as EC, the mean value of salinity in Remah is 3,350 mg/L whereas it is much higher in Al Khatim 11,770 mg/L. Geospatially, the higher salinity was observed in Al Khatim at the south, whereas in Remah higher salinity is recorded in the north (Figure 13). The salinity of groundwater dictates its suitability for irrigation purposes.

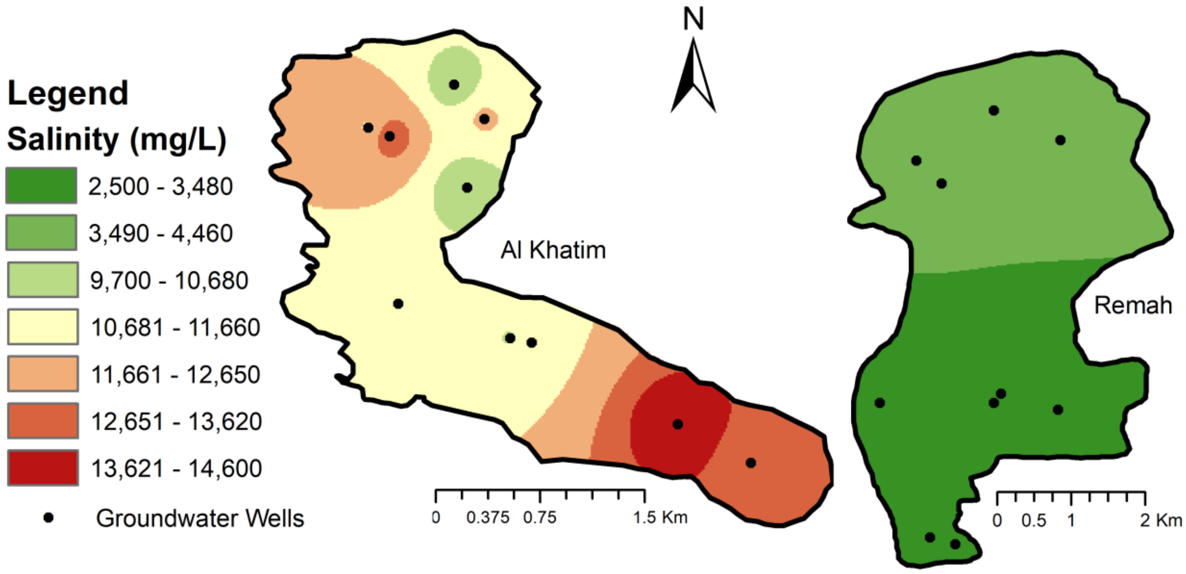

Figure 13: Spatial distribution map of Salinity

4.1.2 Hydrogen-ion Concentration (pH) and Temperature

The pH is the common indicator to check the acidity of water, so it shows the amount of dissolved carbon dioxide CO_2, the carbonate CO_3^{2-}, and bicarbonate HCO_3^-. A pH value lower than 7 indicates acidity and a higher number indicates alkalinity. Values of pH in the Remah region range from 4.48 to 7.16, which depicts that the water is acidic to slightly alkaline. In the Al Khatim region, the pH value lies between 5.02 to 7.03, representation water quality-acidic to neutral (Figure 14).

There are many factors that influence the pH when the water gets in contact with them. These factors include the bedrock, soil composition, and the organic matter (Jardine et al., 1989). The permissible value of pH according to WHO (2004) is between 6.5 to 8.5. All the groundwater samples in the Remah and Al Khatim are in the permissible limit.

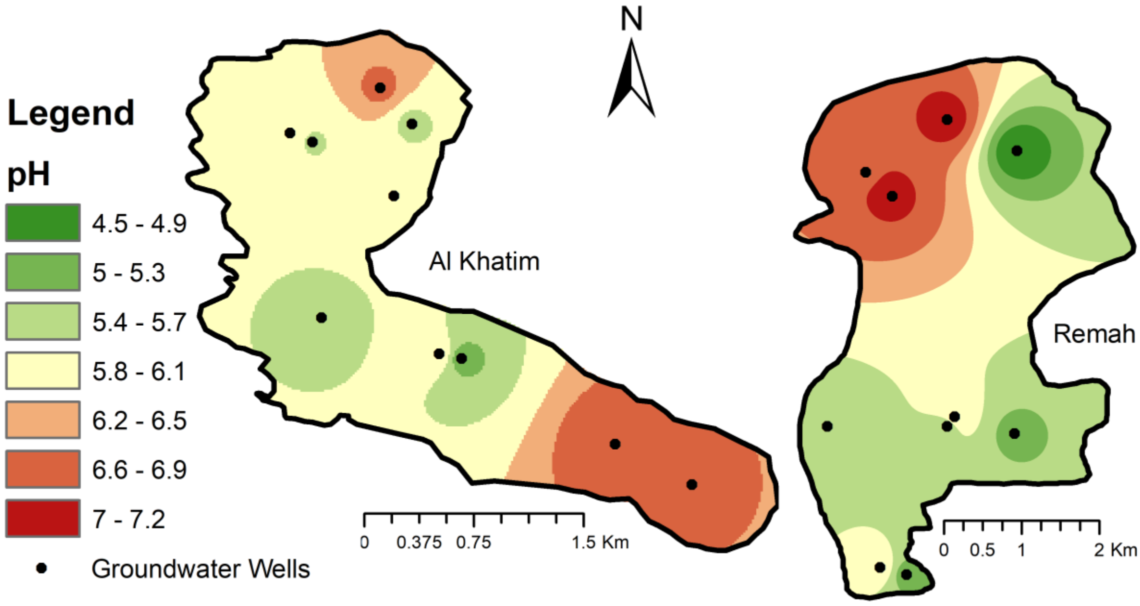

Figure 14: Spatial distribution map of pH

The temperature of groundwater is important to understand the physical and chemical behavior of the aquifer system. The groundwater temperature at the time of collection in Al Khatim region has an average temperature of 31.6 °C whereas the average temperature recorded in Remah samples was 34.6 °C.

4.2 Chemical Properties

The chemical properties of groundwater are influenced by the source rock and soil composition. The major cations investigated in the groundwater samples are sodium (Na^+), potassium (K^+), calcium ($Ca^{2+)}$, and magnesium (Mg^{2+}); major anions including chloride (Cl^-), sulphate ($SO4^{2-}$), bicarbonates (HCO_3^-), and nitrates (NO_3^{2-}). Previous research by Murad et al. (2012) observed that concentration of cation ions was higher and exceeds 5% in the eastern region of UAE (Al Ain). Such imbalance charges indicate higher salinity in this region. The cation charge imbalance is too high in the eastern region of Abu Dhabi which can be attributed to the high salinity in groundwater (Murad and Krishnamurthy, 2004; Murad et al., 2012).

4.2.1 Sodium Concentration

Sodium is abundant in the earth and it is highly soluble. It is found in most rocks and soils. The groundwater absorbs the sodium when it comes in contact with the rocks and soil having sodium abundance.

Sodium concentration in Remah was observed higher in the north and it decreases towards the south with a mean value of 694.9 mg/L, whereas in Al Khatim region it is higher in the south with a mean value of 2,452.6 mg/L (Figure 15). The concentration of sodium has an important role in the evaluation of groundwater quality for irrigation because it increases the hardness of soil and the reduction in its permeability (Tijani, 1994).

The maximum permissible limit for sodium ion in the drinking water is 200 mg/L (WHO, 2004). The results from Remah and Al Khatim shows that they exceed the WHO permissible limits and thus water is unsafe for drinking. An interesting observation shows that sodium concentration in Al Khatim is four times higher than Remah.

Higher concentration of sodium indicate pollution from source or sea water intrusion. Since, the Al Khatim study area is far away from the sea, therefore sea-water intrusion can be neglected. There can be two possible reasons for this higher concentration of sodium, either due to natural source of dissolution of clay minerals feldspars, evaporation from shallow aquifer or anthropogenic sources including agricultural, and or industrial effluents. The higher concentration of sodium can be attributed to evaporation from shallow aquifer, and intense agricultural activities. These are explained in more details in Chapter 5.

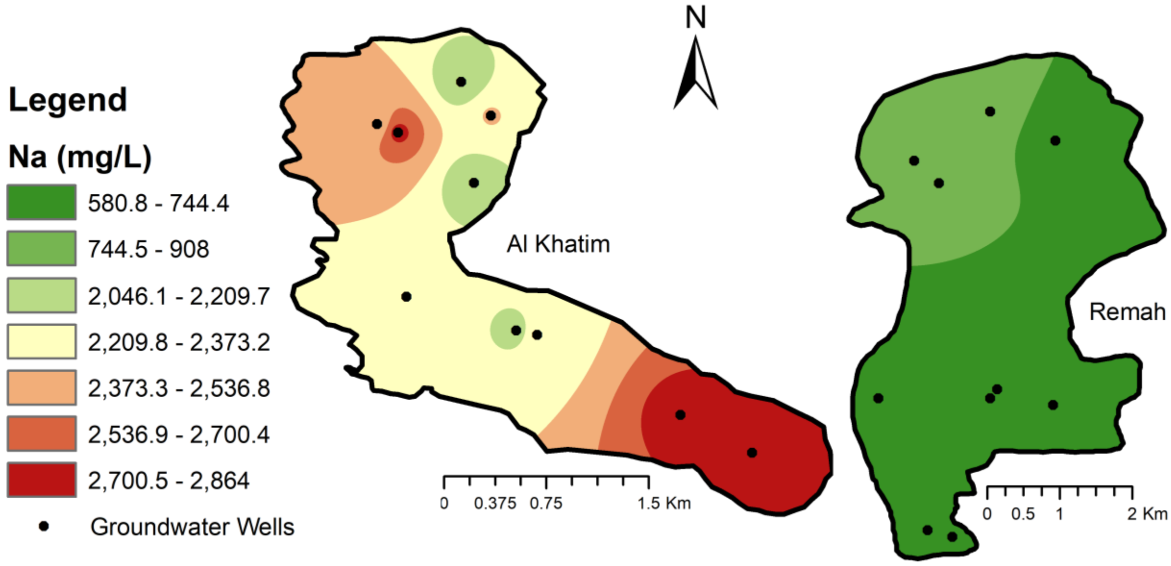

Figure 15: Spatial distribution map of Sodium

To check the reliability of estimated results, the relationship between sodium and chloride for Remah (R^2: 0.88) and Al Khatim (R^2: 0.78) were developed as shown in figure 16.

The higher values for both Remah (R^2: 0.86) and for Al Khatim (R^2: 0.75) provide strong evidence to conclude that the presence of sodium and chloride ion is present from the same source and it is due to extensive agricultural activities. Similar positive relationship (R^2: 0.81) of sodium and chloride ions in the neighboring region of Al Ain was also reported by (Murad et al., 2012). Moreover, increasing agricultural and landscaping activity also has an impact on increasing EC and salinity.

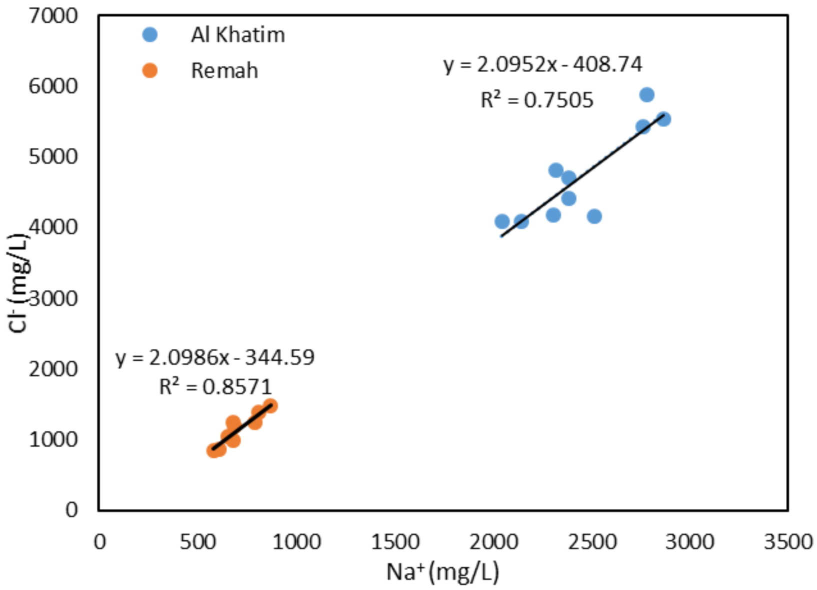

Figure 16: The relationship between sodium and chloride concentration in Remah and Al Khatim

4.2.2 Calcium Concentration

Calcium is found in limestone ($CaCO_3$), gypsum ($CaSO_4.2H_2O$), and anhydrite ($CaSO_4$) which gives dolomite and calcite. Calcium is found in abundance in igneous rocks and is dissolved in the water.

Calcium concentration recorded in the samples of Remah has an average value of 136.9 mg/L, the quality maps show the higher concentration in the north of Remah and it decreases towards the south (Figure 17). In Al Khatim samples, the concentration was much higher as compared to Remah. The average concentration in Al Khatim is 683.8 mg/L where the higher concentration can be seen in the north of Al Khatim region and lower concentration in the south. With the movement of groundwater through the vadose zone, it interacts with the soil and rocks and dissolves them (Ahmed and Clark, 2016). The most common form of calcium in groundwater is because of the limestone or dolomite dissolution.

The calcium permissible limit for drinking water ranges from 75 to 200 mg/L (WHO, 2004). The average concentration in Remah (136.9 mg/L) falls in the permissible limits but not all samples are under WHO limits with few samples exceeding 200 mg/L. Whereas, the concentration in Al Khatim is much higher than the permissible limits and is not acceptable for drinking purposes.

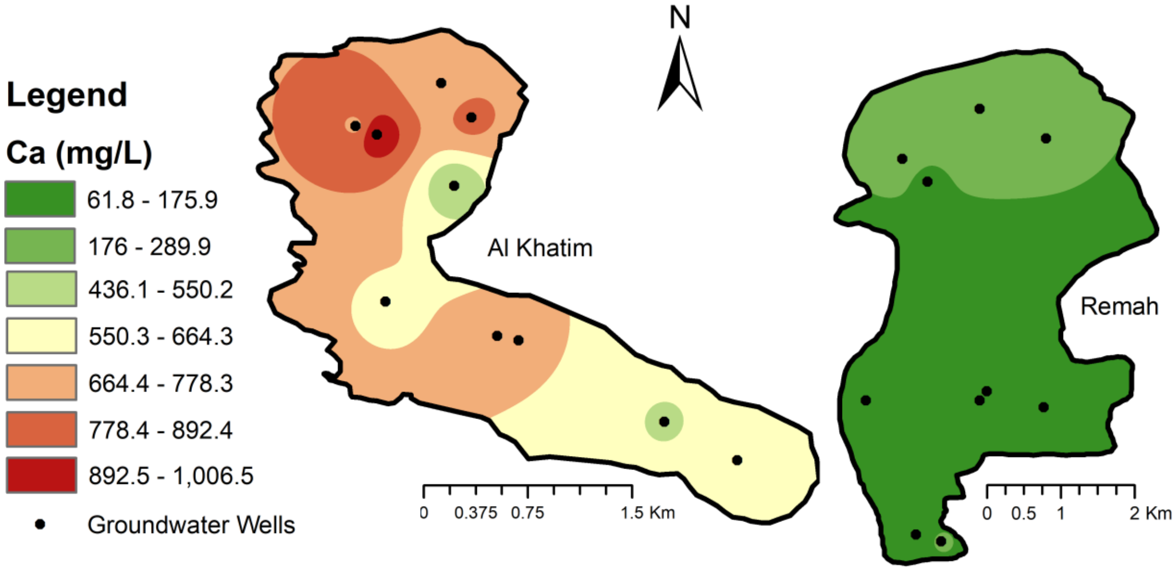

Figure 17: Spatial distribution map of Calcium

4.2.3 Magnesium Concentration

Magnesium is another major cation found in groundwater. There are many source rocks that contribute to the higher concentration of magnesium including gypsum, dolomite, magnesite and or clay minerals (Murad et al., 2012). Due to the low geochemical abundance of magnesium, its concentration in water is less as compared to calcium.

Magnesium ion concentration can be seen, in the spatial distribution map (Figure 18), higher in the north of Remah and decreases towards the south but the overall mean concentration is higher in Al Khatim (mean: 124.7 mg/L) than Remah (mean: 29.2 mg/L).

Specifically, in Al Khatim the higher concentration of magnesium ion can be seen in the south and it decreases towards north. The magnesium concentration is higher in the groundwater because of the dissolution of dolomite rock.

The permissible limit for magnesium in the drinking water ranges between 30 mg/L and 150 mg/L (WHO, 2004). The average concentration of magnesium in both the study area fall in the acceptable limit of WHO, which indicates that groundwater in both study areas of Remah and Al Khatim has no magnesium hazard.

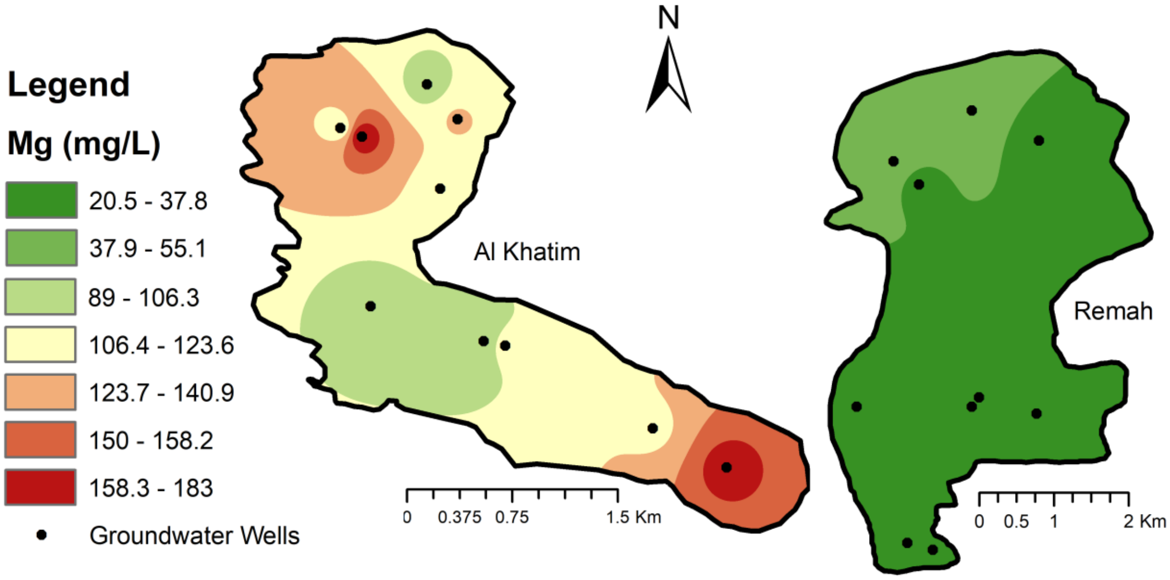

Figure 18: Spatial distribution map of Magnesium

Magnesium and sodium in both the study area (Figure 19) has good relationship (Remah: 0.79; Al Khatim: 0.71). These two parameters together, as an iconic salt, increases from the same source which is agricultural activity. Intensive use of groundwater results in the accumulation of magnesium in the same area which then increases the magnesium concentration of groundwater. However, agricultural fertilizer that are used for different yield also contain fertilizer (Richards, 1954).

The positive correlation of TDS with magnesium (Figure 20) in both study areas (Remah: 0.6; Al Khatim: 0.65) also shows that magnesium is one among the main contributors to the total dissolved solids.

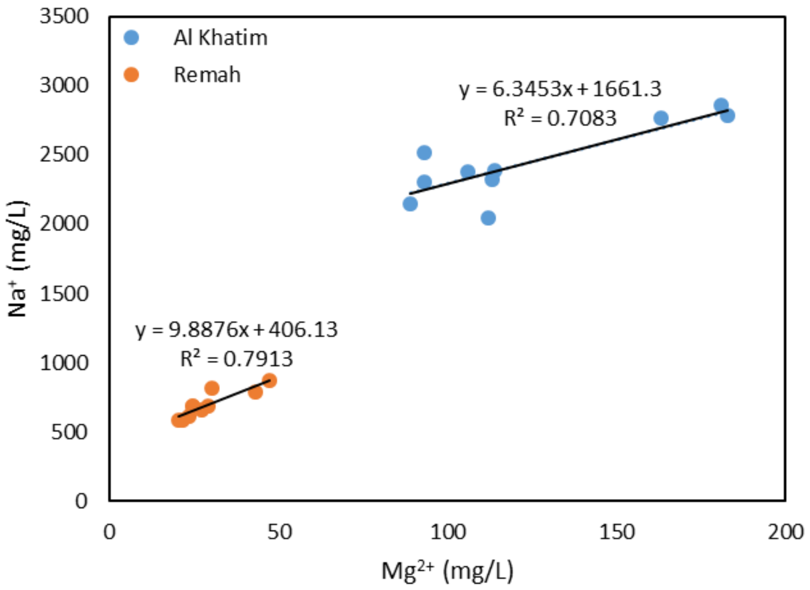

Figure 19: The relationship between magnesium and sodium concentration in Remah and Al Khatim

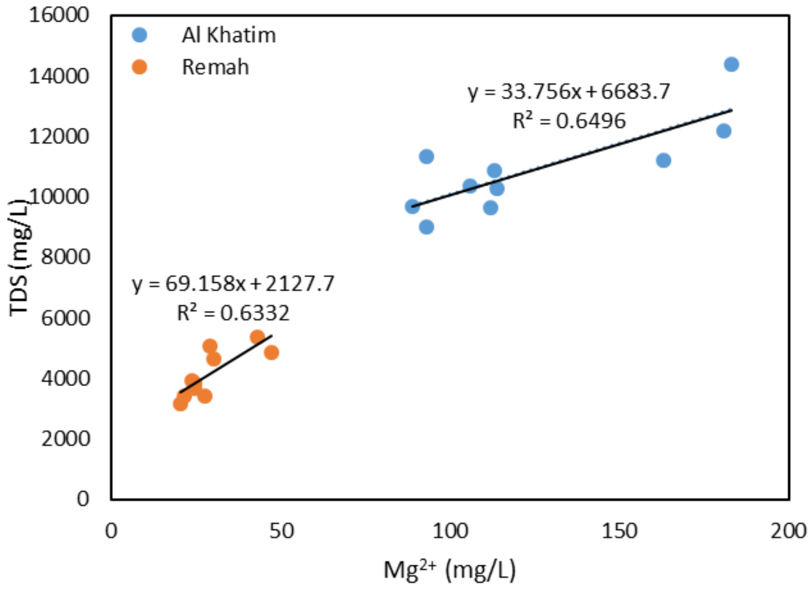

Figure 20: The relationship between magnesium and TDS in Remah and Al Khatim

4.2.4 Potassium Concentration

Potassium is also common element found in groundwater. The concentration of potassium increases in groundwater with the dissolution of rocks. The source of potassium ion in groundwater are the igneous rocks as feldspars (orthoclase and microcline), sedimentary rocks as silicate, some mica and clay minerals (Khalifa, 2003). The abundance of potassium is mostly due to presence of clay in arid environment (Murad et al., 2012).

Potassium concentration in the collected samples of two study areas shows the average potassium ion concentration in Remah region is 15.6 mg/L and the concentration at Al Khatim is comparatively higher with mean value of 27.4 mg/L. The quality maps indicate higher potassium concentration in the north of Remah whereas in Al Khatim higher concentration is in the south (Figure 21). The overall comparison of the two-study area shows that potassium concentrations increases from Remah (East) to Al Khatim (West). The safe limit of potassium in drinking water is 10 mg/L (WHO, 2004). The groundwater samples from both study areas shows elevated potassium concentration and thus are not suitable for drinking purpose.

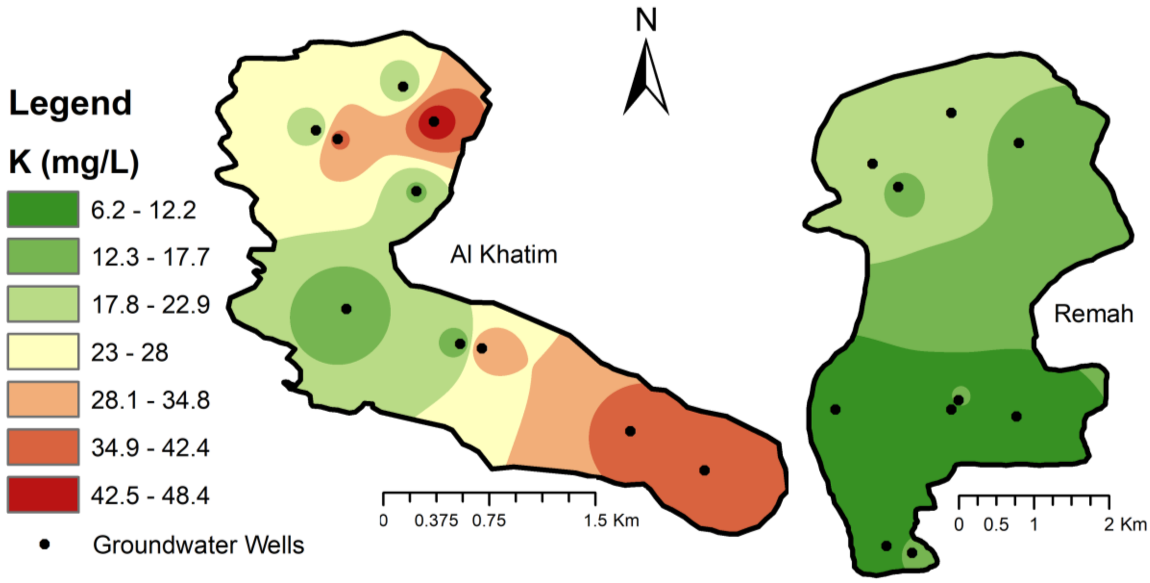

Figure 21: Spatial distribution map of Potassium

The overall comparison shows that study area Al Khatim has comparatively higher concentration of potassium as compared to Remah. This could be due to interaction of groundwater with feldspar, silicate, and clay minerals. Anthropogenic activities such as agricultural fertilizer, that contains potassium as main component, also contributed to the increased potassium in the groundwater samples.

The sodium and potassium are added in the fertilizer as they are the important nutrients of plants. The positive correlation of TDS and potassium (Figure 22) in Remah (R^2: 0.84) and Al Khatim (R^2: 0.68) shows that potassium is one among the other main contributor to the total dissolved salts.

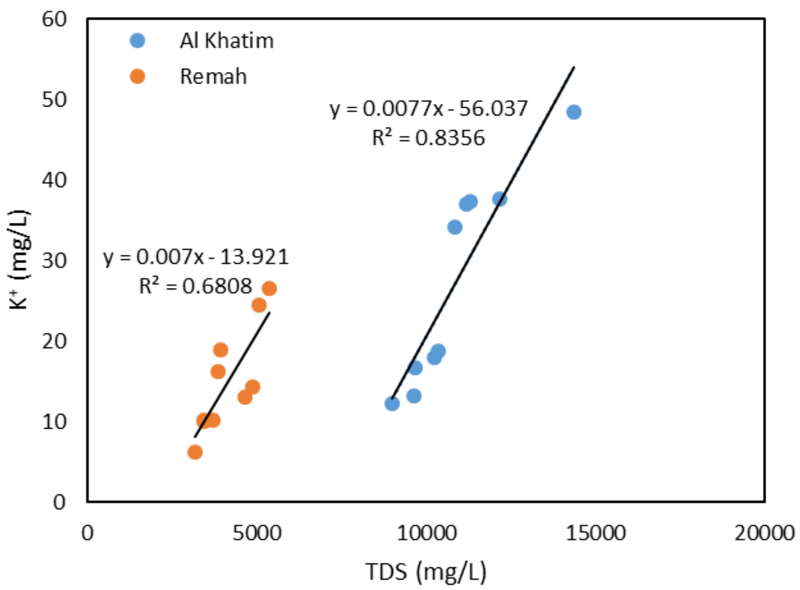

Figure 22: The relationship between TDS and potassium in Remah and Al Khatim

4.2.5 Chloride Concentration

Chloride is one of the major constituents found in the groundwater in arid and semi-arid regions. The chlorides are found in abundance in feldspathoid, sodalite, apatite (phosphate mineral), and evaporites (sedimentary rocks) (Murad et al., 2012). The chloride reacts with different compounds to form salts such as sodium chloride, calcium chloride, and potassium chloride.

Chloride concentration spatial distribution map also shows almost a similar pattern as in the sodium ion (Figure 23), where the concentration of chloride ion (mean: 1,115.5 mg/L) is higher in the north of Remah and it is higher in south and north-west in Al Khatim region (mean: 4,729.9 mg/L). Overall pattern of higher concentration can also be seen in the chloride, where it is lower in Remah and higher in Al Khatim. The drinking water limit for chloride concentration set by WHO (2004), range between 200 mg/L to 600 mg/L. In both study areas (Remah, Al Khatim), the concentration is much higher than the permissible limit of WHO which shows that this water is not safe for drinking purpose.

The higher concentration of chloride can be explained by the natural activities, such as dissolution of feldspathoid, sodalite, apatite, and evaporites. However, the anthropogenic activities such as agricultural practices are the main contribute in the increased chloride concentration in Al Khatim and Remah.

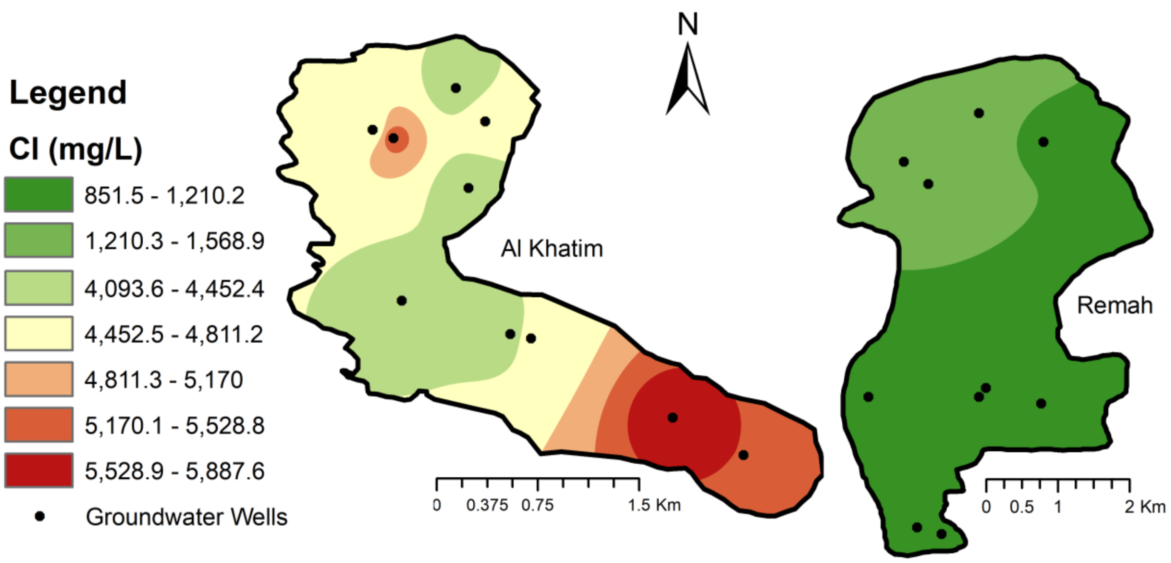

Figure 23: Spatial distribution map of Chloride

4.2.6 Sulphate Concentration

The natural source of sulphate in the groundwater are the volcanic and sedimentary rocks. The type of sedimentary rocks Gypsum ($CaSO_4.2H_2O$) and anhydrite ($CaSO_4$), which is present in the study area, provide groundwater with sulphate (Murad et al., 2012). When the water interacts with these rocks, it gets oxidized and sulphate is dissolved in the groundwater.

The concentration of sulphate ranges from 1,14.3 mg/L to 2,015.9 mg/L in Remah with the mean of 1,512.6 mg/L. The spatial quality map (Figure 24) shows that concentration of sulphate is higher in north of Remah and lower in south. In the study area Al Khatim, the concentration ranges from 2,827 mg/L to 5,457 mg/L with a mean of 3,632 mg/L. The spatial distribution shows the concentration is higher in the south and decreases towards north. However, there is one sample in the north which displays higher concentration.

The permissible limit of sulphate in the groundwater ranges between 200 mg/L to 400 mg/L (WHO, 2004). The concentration of sulphate in both areas is higher than permissible limit and is not suitable for drinking purpose.

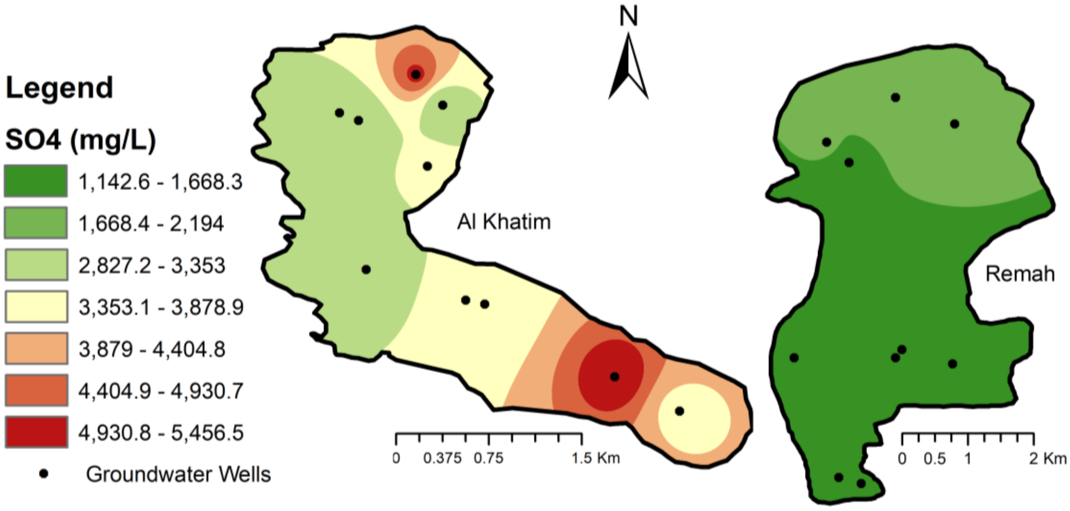

Figure 24: Spatial distribution map of Sulphate

The weak correlation between sulphate and chloride (Remah: 0.28; Al Khatim: 0.07) shows that both anions has different source (Figure 25). Thus, the source of sulphate in the groundwater could be gypsum and anhydrite.

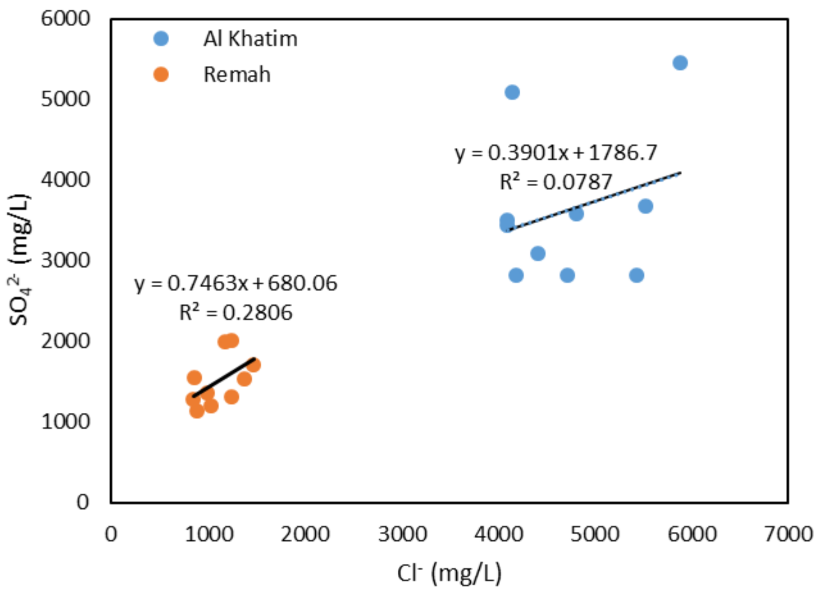

Figure 25: The relationship between chloride and sulphate in Remah and Al Khatim

4.2.7 Bicarbonate Concentration

Bicarbonate are easily dissolved in water. Bicarbonate in the groundwater are derived from carbon dioxide in the soils and atmosphere, and also by the dissolution of carbonate rock (Murad et al., 2012).

The spatial distribution of bicarbonate shows lower concentration in the south and north-west of Remah with the mean value of 39.3 mg/L (Figure 26). However, the bicarbonate concentration in Al Khatim is higher in the north with an average concentration of 104.3 mg/L. The permissible limit for drinking water is 300 mg/L (WHO, 2004). All the samples of Remah and Al Khatim fall within WHO permissible limits.

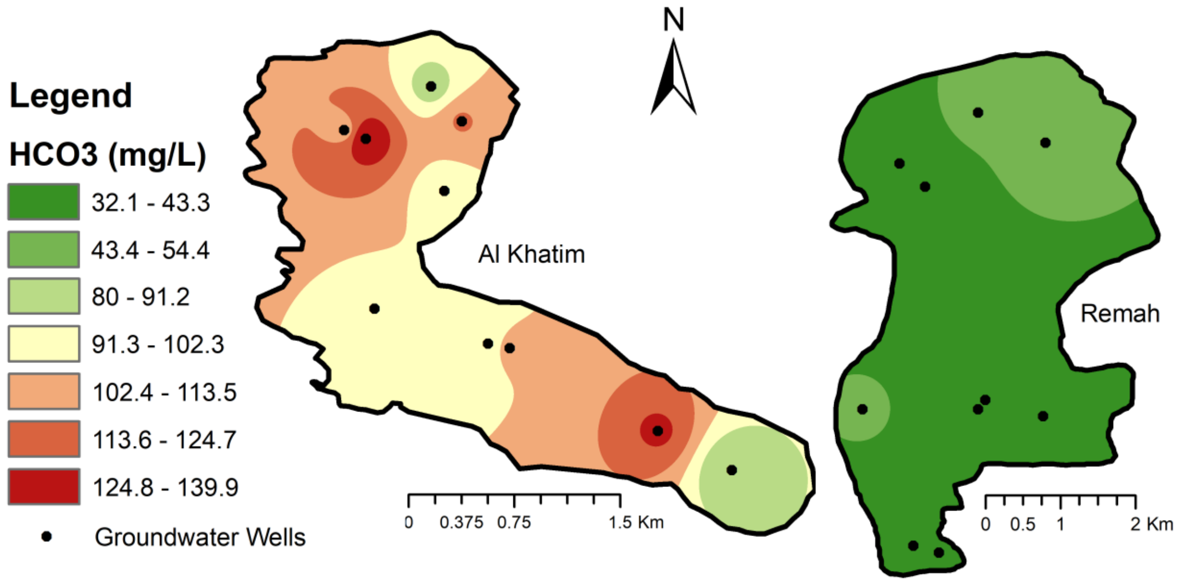

Figure 26: Spatial distribution map of Bicarbonate

4.2.8 Nitrate Concentration

Nitrate is considered as the most important nutrient for plants. The source of nitrogen by-products used in the agriculture are the human wastes, animal manures, sewage sludge, and crops fertilizer. Nitrate (NO_3^-) and ammonia (NH_4) are the most recognized inorganic nitrogen. Usage of nitrogenous fertilizer in excess amount lead to nitrate leakage to groundwater (Weil et al., 1990).

The spatial quality maps show higher concentration of nitrate in the south, the mean value of nitrate in Remah is 96.4 mg/L. In Al Khatim quality, the concentration is higher in the north and it decreases in the south (Figure 27). The mean of all the samples in Al Khatim shows nitrate as 315.7 mg/L. The concentration is comparatively lower in Remah and higher in Al Khatim. The drinking water permissible limit shows that the nitrate concentration should not exceed 45 mg/L (WHO, 2004). The data for both areas shows that it exceeds permissible limit.

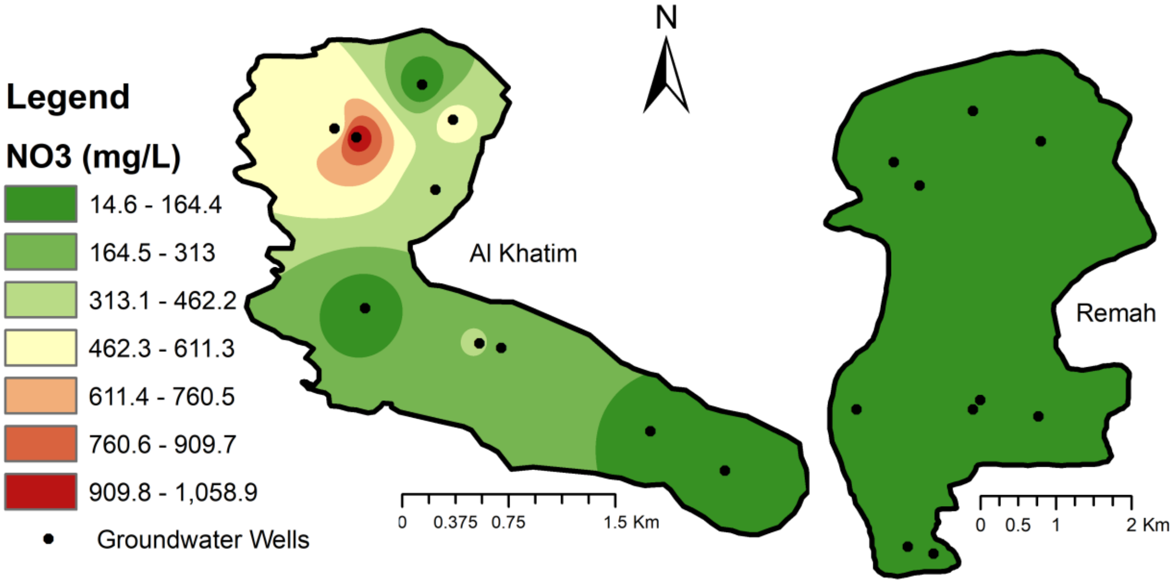

Figure 27: Spatial distribution map of Nitrate

According to Murad et al (2012), the higher relationship between potassium and nitrate indicate agricultural source which is contributing to concentration of potassium and nitrate in groundwater. However, the weak and negative correlation (Figure 28) in both the study areas indicate that the source for nitrate is not agriculture. Since the study area contain poultry farms, and camel farms. It is therefore the animal manure and the underground septic tanks that is contributing to the concentration of nitrate in both the study areas.

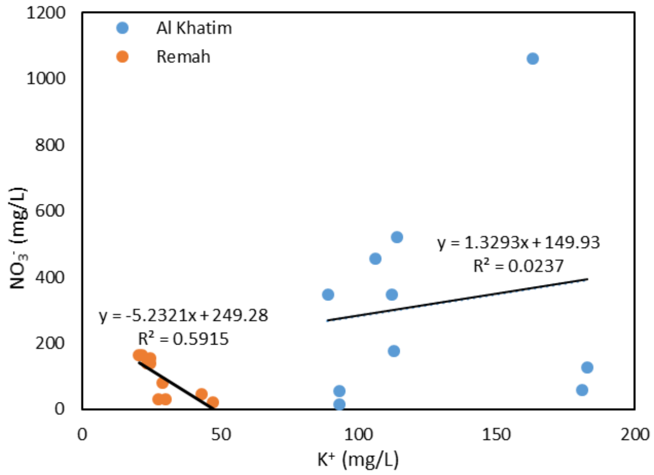

Figure 28: The relationship between potassium and nitrate in Remah and Al Khatim

4.3 Trace Metals

The presence of higher concentration of heavy metals in the groundwater poses a serious hazard to human health. The source of trace metals is mostly anthropogenic, such as the effluents from the industry. The concentration of these heavy metals is compared to the WHO (2011) drinking water guidelines (Table 2).

Table 2: Descriptive statistics for heavy metal concentration in groundwater in Remah and Al Khatim

Remah					
Parameter (mg/l)	**Min**	**Max**	**Mean**	**CV**	**(WHO, 2011)**
Cd	0.25	0.96	0.6275	69.89%	0.003
Zn	0.005	0.009	0.0073	20.41%	5
Cr	0.004	0.006	0.0053	12.1%	0.05
Pb	<0.01				<0.01
Al Khatim					
Cd	0.052	0.996	0.4293	78.8%	0.003
Cr	0.005	0.006	0.0055	9.12%	0.05
Zn	0.007	0.009	0.0082	19.4%	5
Pb	<0.01				<0.01

Units are in mg/L

The data for chromium in both Remah and Al Khatim shows low variability and they were found to be below the WHO standard guidelines. The zinc concentration in Remah shows moderate variability, whereas in Al Khatim it shows low variability. The zinc values were also found below the standard WHO values. The concentrations of lead in both Remah and Al Khatim were below the detection limit of 0.01 mg/L, which is in accordance with WHO guideline limits (WHO, 2011).

Cadmium data is exceeding the WHO (2011) guidelines and thus quality maps were developed only for cadmium (Figure 29). The concentration of cadmium reported high variability in both Remah and Al Khatim regions. The quality maps show a higher concentration of cadmium in the north of Remah and it decreases towards the south. In Al

Khatim higher concentration can be seen in the south and north-east. The analysis shows that cadmium exceeded the WHO guidelines values in all the collected samples.

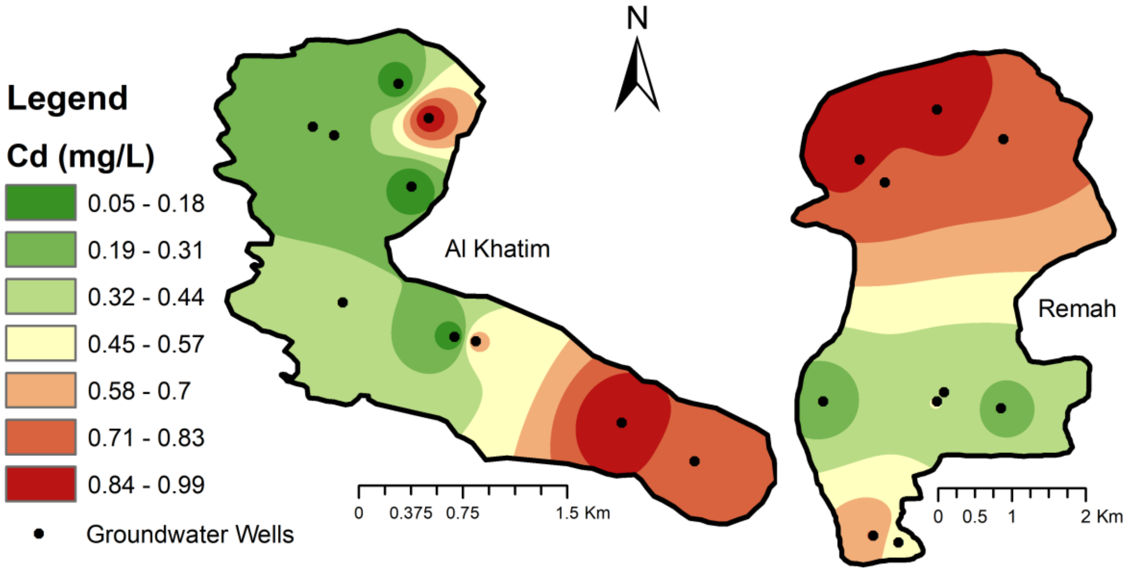

Figure 29: Spatial distribution map of Cadmium

4.4 Groundwater Levels and Salinity

Groundwater level was measured below the ground level (GL) for all the groundwater wells. The level of groundwater in Remah region ranges between 102.5 m to 197.98 m with an average water level of 155.5 m. The deep-water level was recorded in Remah region as compared to Al Khatim. In the Al Khatim region, the water level varied from 17.1 meters to 42.2 m with an average of 32.6 m.

In Al Khatim region salinity level is observed higher (mean: 11,770 mg/L) where the water table is shallow (mean: 32.6 m), and comparatively in Remah less salinity (mean: 3,350 mg/L) was measured where water table is deep (mean: 115.5 m) (Figure 30). The possible reason for higher salinity in Al Khatim could be due to the evaporation of water from the shallow aquifer.

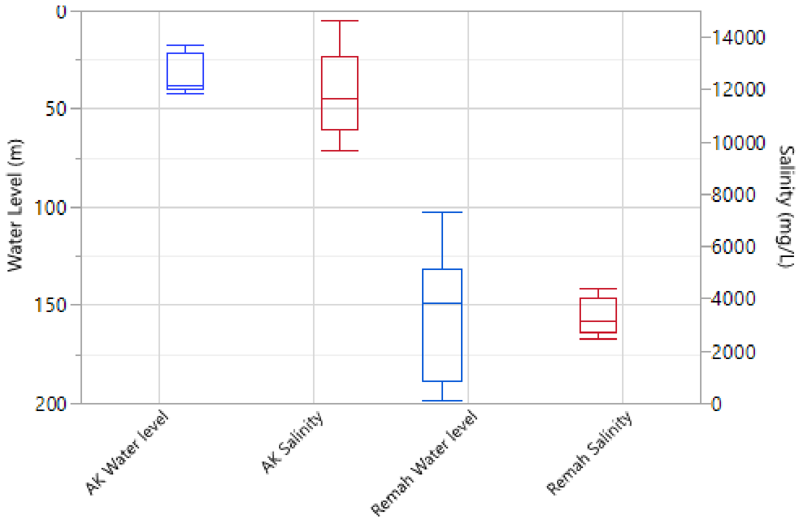

Figure 30: Box plot comparison of groundwater levels and salinity

4.5 ^{222}Radon (as ^{238}U daughter)

Radon (^{222}Rn) is a radioactive noble gas, which is colorless and odorless and occurs naturally in water, air, rocks, and soils (Pinti et al., 2014). ^{222}Rn is the daughter isotope of ^{238}U. The decay of ^{222}Rn results in the alpha-particles. They are potential health hazards if inhaled or ingested (Pinti et al., 2014). It causes lung cancer when inhaled or ingested in higher concentration. The ^{222}Rn has higher affinity to salinity, which means that the concentration of ^{222}Rn will be higher where there is saline water (Lieberman, 2013). Therefore, it is observed that in general the ^{222}Rn concentration average is higher in Al Khatim where the salinity is higher, whereas it is lower in Remah where the salinity is lower. The descriptive statistics of ^{222}Rn in the groundwater samples of Remah and Al Khatim is given in Table 3. The complete data is available in appendix C.

Table 3: Descriptive statistics of ^{222}Rn in groundwater in Remah and Al Khatim (CV: coefficient of variation)

Study Area	Min	Max	Mean	CV	(WHO, 2011)	(EPA, 2012)
Remah	2.5	14.2	7.1	52.1%	100	11.1
Al Khatim	1.4	24.5	7.6	97.4%	100	11.1

Units are in Bq/L

The quality map for ^{222}Rn shows higher concentration in north of Remah with an average concentration of 7.1 Bq/L. In Al Khatim study area, higher concentration can be seen in the north and south with a mean value of 7.6 Bq/L (Figure 31).

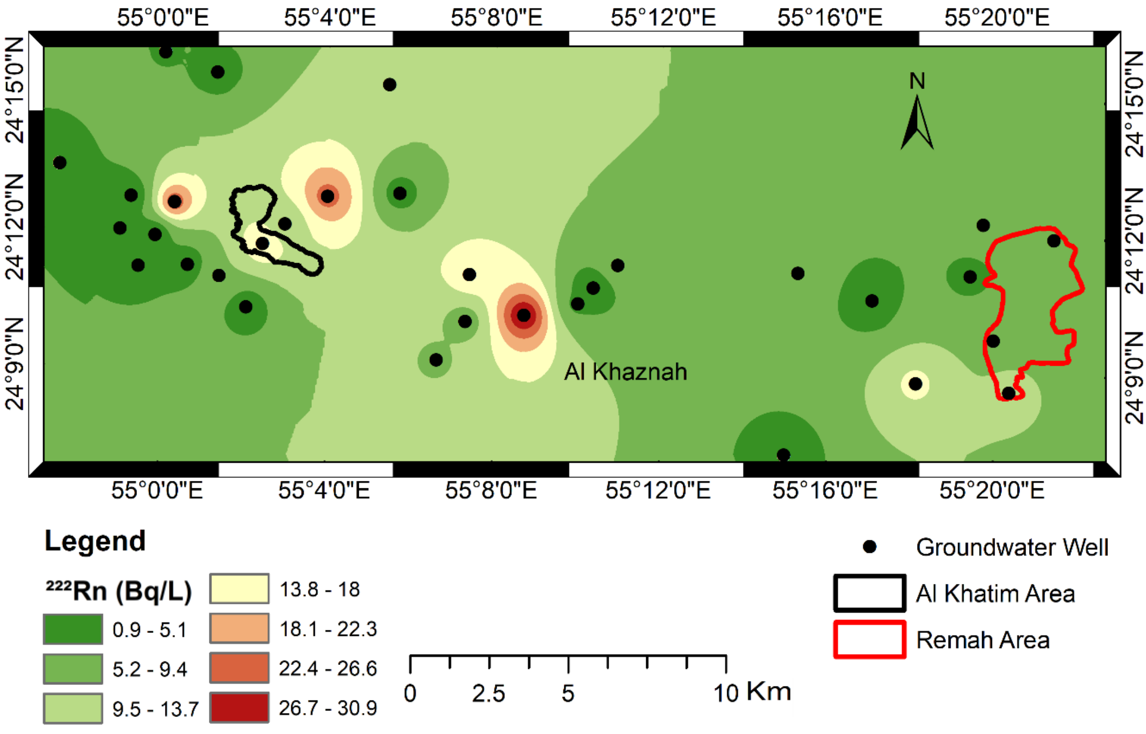

Figure 31: Spatial distribution map of $^{222}Radon$

The permissible limit in the groundwater according to WHO (2011) is 100 Bq/L whereas EPA (2012) shows value of 11.1 Bq/L. All the samples of Remah and Al Khatim are under the permissible limit of WHO (2011). Majority of the samples also falls under the EPA (2012) permissible limits except 1 sample (sample 9) in Remah and 3 samples (sample 1,2 and 5) in Al Khatim. As discussed earlier, the salinity in Al Khatim is higher (mean: 11,770 mg/L) and comparatively lower in Remah (mean: 3,350 mg/L); the ^{222}Rn concentration is higher in Al Khatim samples and comparatively lower in Remah.

The coefficient of correlation (R) between Radon-222 and TDS is usually high in carbonate aquifers (Alshamsi et al., 2013), however this correlation is weak in the sand dune aquifer. The correlation coefficient in Remah is -0.3909 and in Al Khatim is 0.0455 (Figure 32).

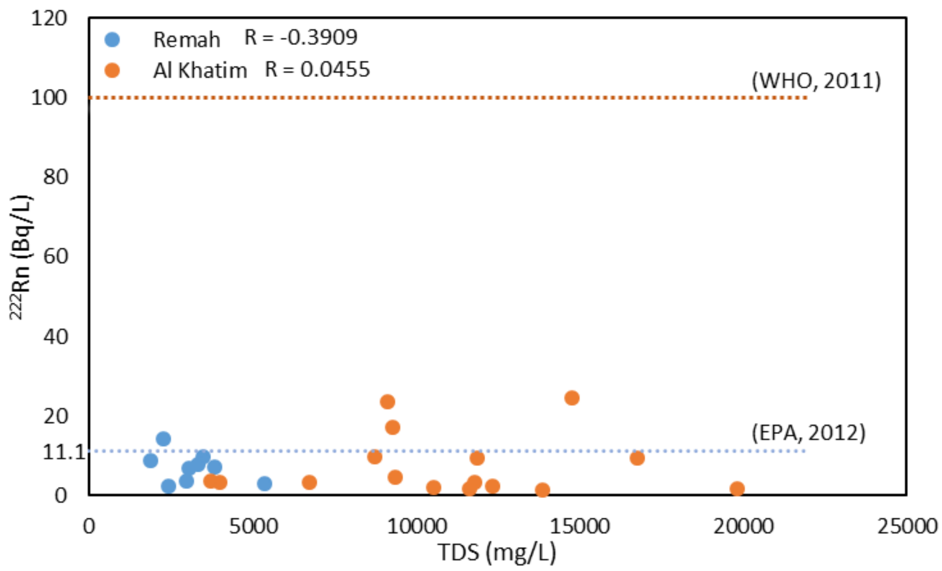

Figure 32: The relationship between TDS and Radon-222 in Remah and Al Khatim (R: correlation coefficient)

4.6 Suitability for Irrigation Use

The study area of Remah and Al Khatim are considered to be the oldest cultivated land in Abu Dhabi Emirate. The groundwater is the main source of water for the agricultural activities. The Wilcox plot is used to access the suitability of groundwater for agricultural purposes. The electrical conductivity in dS/m is plotted against sodium adsorption ratio SAR.

The four categories of sodium hazards (Y-axis) are:

- S1; Sodium Adsorption Ratio is less than 10; Low sodium hazard water
- S2; Sodium Adsorption Ratio is between 10 and 18; Medium sodium hazard water
- S3; Sodium Adsorption Ratio is between 18 and 26; High sodium hazard water
- S4; Sodium Adsorption Ratio is more than 26; Very high sodium hazard water

The four categories of salinity (X-axis) are:

- C1; Salinity is less than 0.25 dS/m; Low salinity water
- C2; Salinity is between 0.25 and 0.75 dS/m; Medium sodium hazard water
- C3; Salinity is between 0.75 and 2.25 dS/m; High salinity water
- C4; Salinity is more than 2.25 dS/m; Very high salinity water

The extended wilcox plot of Remah and Al Khatim falls in C4-S4 (Figure 33), shows that water has very high sodium hazard and it has very high salinity. The results indicate that the groundwater of Remah and Al Khatim area is not suitable for irrigation of traditional crops. This water can be used to irrigate salt tolerant crops.

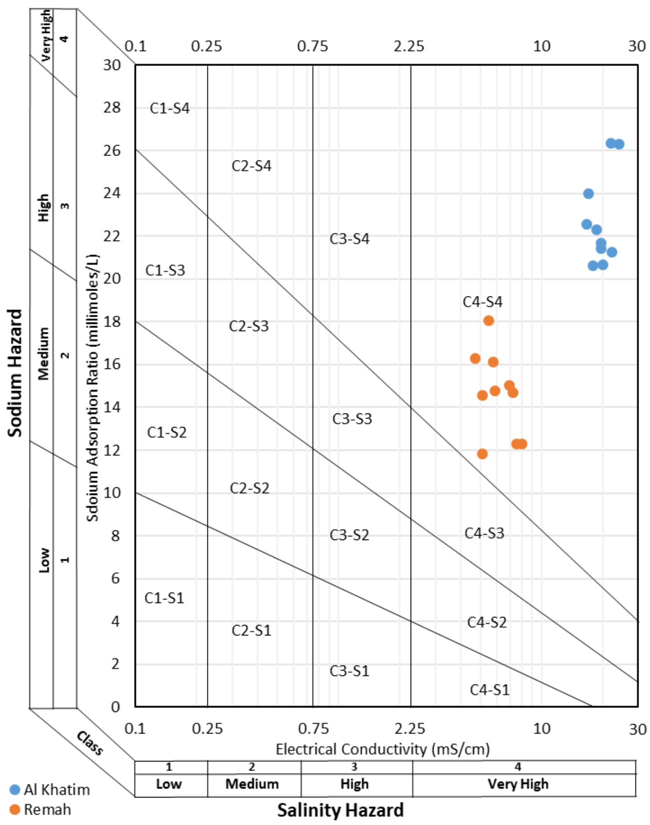

Figure 33: Extended Wilcox plot showing irrigation water classification

The suitability of groundwater for agricultural use in Remah and Al Khatim was assessed using agricultural indexes. Sodium adsorption ratio (SAR) shows a mean value of 65.3. In terms of sodium adsorption ratio, all the samples indicate that groundwater is unsuitable for irrigational purposes in both study areas (Table 4).

Table 4: Groundwater classification for irrigation use

Well I'd	Na%	Salinity Hazard EC (µS/cm)	SAR	MH (%)	KI (mEq/L)
	<20 Excellent	<750 Good	<6 Suitable	<50 Safe	<1 Safe
	20-60 Good	750-2000 Permissible	6-9 Not Suitable		
	60-80 Doubtful	2000-3000 Doubtful		>50 Unsafe	>1 Unsafe
	>80 Unsuitable	>3000 Unsuitable	>9 Completely not suitable		
R1	74%	7,260	14.7	29.5	2.8
R2	76%	6,950	15.0	22.8	3.2
R3	69%	8,030	12.3	22.8	2.2
R4	72%	7,570	12.3	20.8	2.5
R5	71%	5,130	11.8	19.6	2.4
R6	80.7%	5,890	14.8	30.4	4.1
R7	84.8%	5,500	18.1	38.3	5.5
R8	81%	5,110	14.6	30.0	4.2
R9	81.7%	5,760	16.1	30.5	4.4
R10	84.1%	4,710	16.3	35.6	5.3
AK1	74%	22,000	26.3	33.8	2.8
AK2	74.3%	24,200	26.3	36.0	2.9
AK3	70%	19,700	21.7	21.7	2.3
AK4	70%	18,000	20.6	18.1	2.3
AK5	71%	18,700	22.3	19.1	2.5
AK6	74%	16,700	22.6	30.0	2.9
AK7	67%	20,100	20.7	18.8	2.1
AK8	73%	17,100	24.0	18.6	2.6
AK9	69%	19,600	21.4	18.9	2.2
AK10	65%	22,300	21.3	21.2	1.9
Minimum	**65.5%**	**4710**	**11.8**	**18.1**	**1.9**
Maximum	**84.8%**	**24200**	**26.3**	**38.3**	**5.5**
Mean	74.1%	13015.5	18.7	25.8	3.1

R: Remah; AK: Al Khatim

Sodium percentage (Na%) in the six samples of Al Khatim and four samples of Remah are categorized as doubtful whereas the remaining sample showed unsuitability for irrigation purpose. The average Na% is 81.8 in both study areas (Table 4). Thus Na% indicates that water in both areas is unsuitable for irrigation purposes.

Salinity Hazard (EC) shows the amount of salinity in the water with the range of more than 3000 µS/cm is unsuitable for irrigation purpose (Table 4). The average salinity in Remah is 6,200 µS/cm and in Al Khatim 19,800 µS/cm. Among the total 20 samples, all the sample shows electrical conductivity higher than 3000 µS/cm. Thus, the overall results show that water is also not suitable in terms of salinity for both the study areas.

Magnesium Hazard (MH) value in all the samples of both study areas is less than 50% (Table 4), thus it indicates that the alkalinity of groundwater is in permissible limits. The mean value of MH in all the samples is 20.3%. This index indicate that water is safe to be used for agricultural purpose from magnesium hazard perspective.

Kelly's Index (KI) in all the samples (Table 4) shows value greater than 1 which indicates that water is unsafe for agriculture activities.

Chapter 5: Discussion

The hydrogen ion concentration is the measure of its acidity or alkalinity. The pH value of water affects its quality and its usage for different purposes. The pH in water is controlled by the presence of alkalinity (bicarbonates HCO_3^- and carbonates CO_3^{2-}) and acidity (dissolved carbon dioxide CO_2). The moderately and slightly acidic characteristics of groundwater quality in Remah and Al Khatim areas highlight the extensive use of fertilizers in the irrigation which has affected the groundwater.

The temperature of groundwater increases from the west (study area) to Al Ain, opposite to the direction of groundwater flow (Murad et al., 2012). This pattern was also observed in the collected groundwater samples in our study area, where the mean temperature at Al Khatim (West) which was recorded 31.6 °C is less as compared to the mean temperature of 34.6 °C in Remah (East).

Schoeller diagram was used to classify the concentration of water quality parameters (Mg, Ca, Cl, SO_4, Na, K, and HCO_3,) in different samples (Scholler, 1965) as shown in figure 34. The different water quality parameters are plotted for both Al Khatim and Remah in mg/L. The higher concentration of sulphate and chloride ions and lower concentration of potassium, bicarbonate and magnesium ions in all samples can be clearly observed.

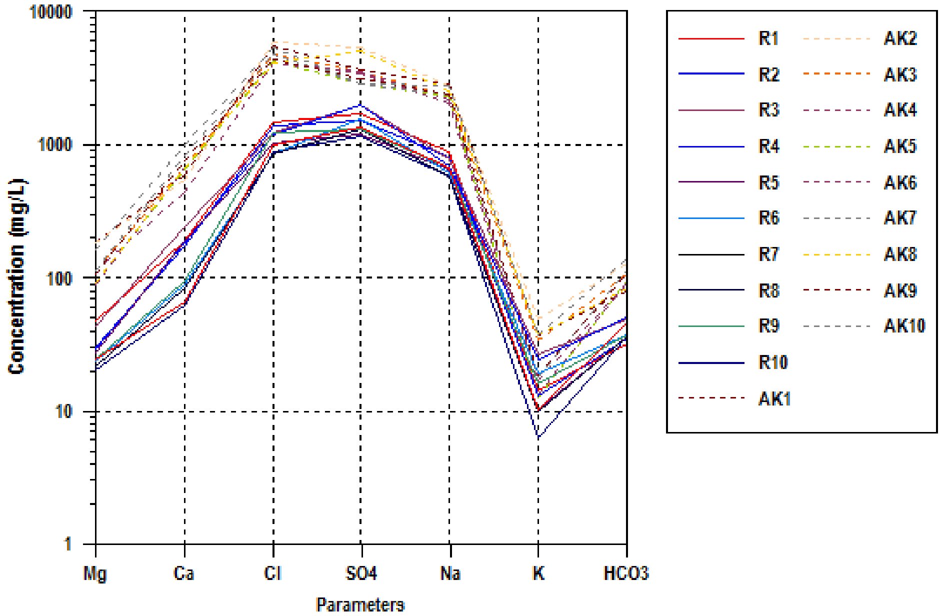

Figure 34: Schoeller plot for collected groundwater samples in Remah (R) and Al Khatim (AK)

As discussed in Chapter 4, the concentration of Sodium and Chloride are much higher as compared to WHO (2004) permissible guidelines. The higher value of R^2 value (0.75) of Al Khatim and Remah (R^2: 0.86) is a strong evidence that groundwater is used for irrigation. This positive correlation was also studied by Murad et al. (2012) in Al Ain region.

The presence of calcium in groundwater is due to the dissolution of limestone or dolomite. The calcium dissolution from Hafeet Mountain was reported by Murad et al. (2012), with 1813 mg/L near Hafeet Mountain. The results were also compared with Murad et al. (2012) which confirms that limestone strata are reducing from Al Ain towards Remah and Al Khatim areas. Magnesium concentration is generally higher because of the presence of dolomite rock. The result shows low magnesium concentration in Al Khatim and Remah which are under the acceptable range of WHO (2004) drinking water guidelines. The magnesium concentration is usually recorded low in sand dune aquifer due to low presence of dolomite rock (Iqbal et al., 2018). Previous study by Iqbal et al (2018) in the Liwa (Western Region of UAE) also shows no magnesium hazards in the groundwater samples.

The presence of potassium ion in groundwater is due to the interaction of groundwater with orthoclase, microcline, silicate, mica and clay minerals (Khalifa, 2003). The elevated concentration of potassium is due to the agricultural source in Al Khatim and Remah; as potassium is one among the main constituent in the fertilizer used.

The suitability for irrigation was assessed using Na%, SAR, EC, MH, and Kelly's index. The agricultural indexes summary of 20 samples (10 each Remah and Al Khatim) is given in the Table 5. Due to the reduction of dolomite strata, the Mg concentration is less in the groundwater which shows no magnesium hazard in the groundwater. The higher salinity and sodium hazards indicate that water is unsuitable and unsafe for agricultural purposes.

Table 5: Summary of groundwater classification for irrigation use

Parameters	Range	Water Class	No. of Samples
Na%	< 20	Excellent	-
	20-40	Good	-
	40-60	Permissible	-
	60-80	Doubtful	5
	> 80	Unsuitable	15
Alkalinity Hazard (SAR)	< 6	Suitable	-
	6-9	Not Suitable	-
	> 9	Completely not suitable	20
Salinity Hazard (EC)	< 250	Excellent	-
	250-750	Good	-
	750-2000	Permissible	-
	2000-3000	Doubtful	-
	> 3000	Unsuitable	20
Magnesium Hazard (MH)	< 50	Safe	20
	> 50	Unsafe	-
Kelly's Ratio	< 1	Safe	-
	> 1	Unsafe	20

The plot of Ca+Mg and SO_4+HCO_3 should be along the 1:1 if the main reaction is due to the dissolution of dolomite, gypsum, calcite, and anhydrite (Iqbal et al., 2018). The samples of Al Khatim and Remah (Figure 35) can be seen in the ion exchange region and thus no reverse ion exchange is taking place. Due to low concentration of magnesium and its source as agriculture in both study areas, the rock water interaction shifts to ion exchange.

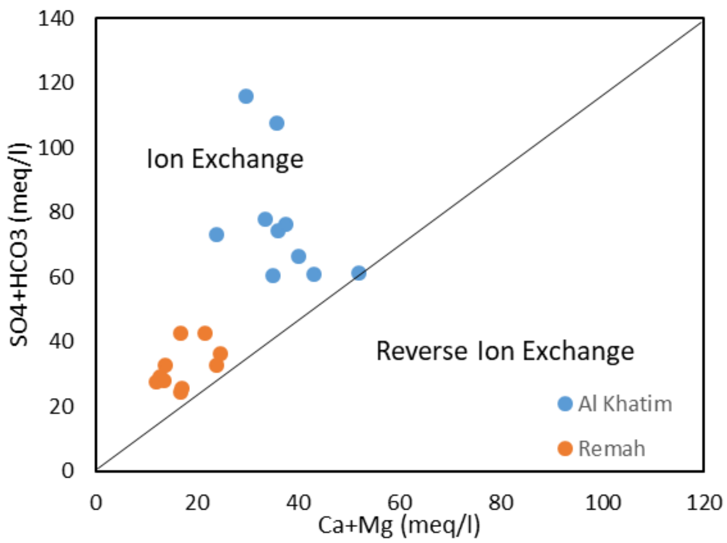

Figure 35: Ca+Mg versus SO_4+HCO_3 plot for Remah and Al Khatim

The relationship between calcium and sulphate concentration (in mEq/L) shows the dominance of sulphate over calcium (Figure 36) in both the study areas. The excess of sodium and chloride when combined with calcium and sulphate forms $CaCl_2$ and Na_2SO_4 type of groundwater.

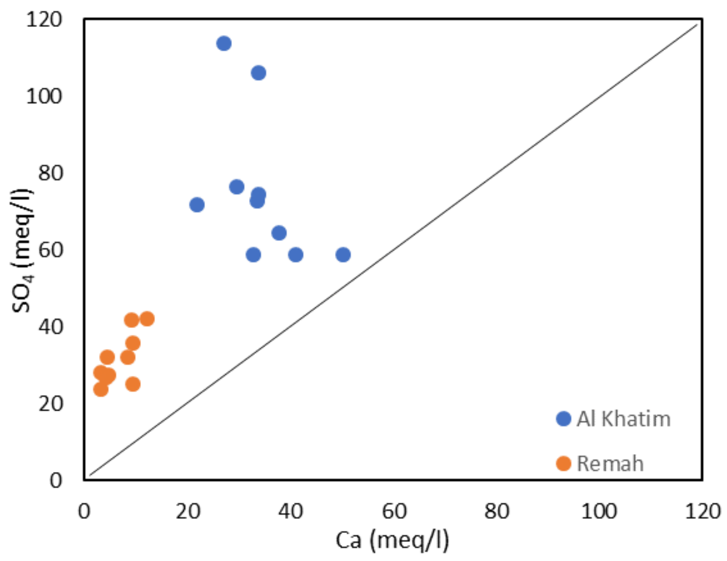

Figure 36: Ca versus SO_4 plot for Remah and Al Khatim

The hydrochemical analysis of groundwater in the Remah area indicate the anions sequence as $SO_4^{2-} > Cl^- > NO_3^- > HCO_3^-$ and cations $Na^+ > Ca^{2+} > Mg^{2+} > K^+$. Whereas in Al Khatin the anions sequence is $Cl^- > SO_4^{2-} > NO_3^- > HCO_3^-$ and cations sequence as $Na^+ > Ca^2$ $> Mg^{2+} > K^+$.

Cadmium enters the groundwater through anthropogenic activities. It is a non-essential toxic metal, which is mostly found in phosphate fertilizers (Bandara et al., 2011). Due to excessive agricultural activities in the study areas, fertilizers are used which is the cause of cadmium in the groundwater. The concentration of chromium, zinc, and lead was found to be below the WHO guidelines which indicates that no heavy metal reaches the study area from Al Saad Industrial area. The trace metal results showed that groundwater is contaminated with cadmium whereas zinc, chromium, and lead falls under the permissible WHO (2011) limits.

The Radon-222 has higher affinity to salts in the carbonate aquifers (Alshamsi et al., 2013). This study shows that in sand dune aquifers the concentration of Radon-222 is less in groundwater. The radioactive study of the two study areas shows no harm to the human health as all the samples were below WHO (2011) permissible limits, however 4 samples exceeded the EPA (2012) permissible limits. Among them 1 was recorded in Remah and 3 samples in Al Khatim.

5.1 Hydrochemical Facies

Hydrochemical facies is a concept that is used to analyze the different chemical characteristics of groundwater by categorizing them according to its chemical components, to explain the chemical reactions that is taking place in that environment. Water type is used to describe hydrochmical facies, it is the representation of dominance of each cations and anions that exceeds 50% of its total anions and cations in mEq%. The 20 samples collected, 10-each from Al Khatim and Remah, shows the following groupings:

1. Na – SO_4 – Cl – Ca (Samples: R1, R2, R3, R4, R5, R6, R7, R8, R9, R10, AK8)
2. Na – Cl – SO_4 – Ca (Samples: AK1, AK2, AK3, AK4, AK5, AK6, AK7, AK9, AK10)

An interesting pattern appears where Sodium, sulphate and chloride is dominant in all sample of Remah and one sample of Al Khatim (AK8), whereas all the sample of Al Khatim is dominant with sodium, chloride, and sulphate except sample AK8. Overall dominance in general is that of sodium and chloride which shows the contaminating of groundwater by agricultural practices. The agricultural waste when mix with groundwater elevate the concentration of sodium and chloride by the process of reverse ion exchange. This shows that the hydrochemistry of groundwater is affected by the agricultural practices. To express the water type more in the study area, samples of both study areas are plotted in piper diagram (Figure 37).

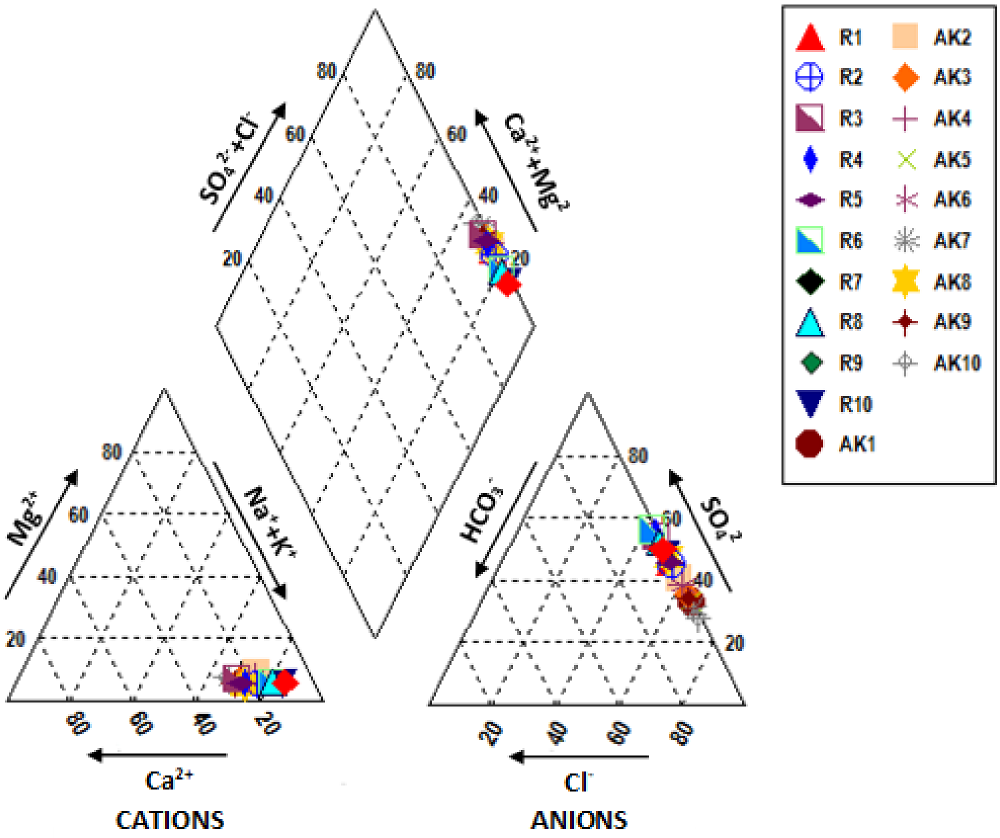

Figure 37: Piper plot for Remah (R) and Al Khatim (AK)

The piper diagram includes two triangles with one representing cations and other anions, and a diamond shape where the cations and anions intersect. The diamond shape represents the mixture of all cations and anions. The piper diagram gives us the percentage of cations and anions with respect to the total percentage concentration. The piper diagram (Figure 40) for both study areas has the following interpretation.

- In cations triangle, samples are settled in sodium and potassium type due to the elevated concentration of sodium.
- In anions triangle, maximum samples are settled in chloride type followed by sulphate.
- The sodium and potassium (strong acid) is exceeding bicarbonate (weak acid). The higher value of sodium can be attributed to the agricultural as a source.

- The chloride and sulphate alkalis are exceeding calcium and magnesium (alkaline earth). The reason behind the elevated concentration of chloride is due to the agriculture source.

The diamond shape shows that all the samples are located in the saline area between 15 and 40 because the identified water type is sodium and chloride. All the samples can be seen lying closer to each other that shows similarity of the water composition.

5.2 Water Genesis and Hypothetical Salt Combination

Water genesis is used to understand the chemical process that affects the groundwater body. The analysis is explained by Sulin's graph that has two equal square. One square represents the marine meteoric genesis which include Na_2SO_4 and $NaHCO_3$ and the other square represents the marine water genesis include $CaCl_2$ and $MgCl_2$. The unit used for the samples are mEq% in their respective anions and cations (Sulin, 1948). All the samples collected in Remah and Al Khatim are identified as meteoric origin.

The meteoric water origin ($\frac{Na}{Cl} > 1$) of Na_2SO_4 water type ($\frac{Na-Cl}{SO_4} < 1$) accounts for all the 20 water samples, reveals the following hypothetical salt combinations:

1. $NaCl > Na_2SO_4 > CaSO_4 > MgSO_4 > KCl$ (Samples: R1, R2, R3, R4, R5, R6, R7, R8, R9, R10, AK8)
2. $NaCl > Na_2SO_4 > CaSO_4 > MgSO_4 > KCl$ (Samples: AK1, AK2, AK3, AK4, AK5, AK6, AK7, AK9, AK10)

There is different salt combination which shows an ion exchange processes in both study areas. The permanent salts like calcium sulphate and magnesium sulphate shows the presence of sulphate and carbonate minerals. The high presence of sodium and chloride ion in all water types shows the infiltration of meteoric water after interaction with irrigation water.

Chapter 6: Conclusions and Recommendations

6.1 Conclusions

The total dissolved content and salinity of the groundwater shows a general decreasing trend from the west (Al Khatim) to the east (Remah). Higher salinity in groundwater in both study areas is due to its extensive use for irrigation. Major cations and anions sequence dominance in Remah area indicate the anions sequence as SO_4^{2-} > Cl^- > NO_3^- > HCO_3^- and cations Na^+ > Ca^{2+} > Mg^{2+} > K^+. Whereas in Al Khatin the anions sequence is Cl^- > SO_4^{2-} > NO_3^- > HCO_3^- and cations sequence as Na^+ > Ca^2 > Mg^{2+} > K^+.

The groundwater in both the regions can be characterized as brackish water. This water is used for agricultural activities as there are many farms in both the regions which confirm the positive relationship between chloride and sodium ions. The groundwater in Al Khatim cause moderate to high harmful effects on the plant as the average salinity is 11,770 mg/L. The magnesium concentration in both study area is less due to the absence of dolomite strata in sand dune aquifer. The average potassium concentration in Al Khatim is also higher as compared to Remah, it shows the presence of clay in both regions is the cause of potassium ion concentration. Limestone strata increases from Hafeet Mountain towards the study area (Murad et al., 2012). The presence of calcium confirms in Remah the average concentration is 136.9 mg/L which increases to 684 mg/L in Al Khatim. Zinc, Chromium, and Lead were reported below the WHO guidelines. Because of the extensive use of fertilizer, the Cadmium concentration is high in Remah followed by Al Khatim. The agricultural indexes (Na%, SAR, EC, MH, and Kelly's index) shows that the water is unsuitable and unsafe for agricultural purposes. The radioactive study of Radon-222 in both study area shows no harm as they fall under the permissible limits set by WHO (2011). The hypothetical salt through water genesis

(Sulins graph) shows that water is meteoric type and there is $CaSO_4$ and $MgSO_4$ salt in addition to NaCl.

6.2 Recommendations

In context of this study, for Remah and Al Khatim, the following recommendations are presented:

1. It is highly recommended to monitor agricultural activities in the study area and periodic assessment of groundwater should be carried out to prevent further deterioration of groundwater.
2. There is need for a model to be established that can monitor the concentration of Radon in irrigation water and the types of crops that are affected with that.
3. A study is recommended that compares the Radon-222 concentration with type of aquifer and depth of aquifer.
4. Strategic plan should be developed to better manage the water resources.
5. Strict rules should be in placed for the quantity of water abstraction and unplanned drilling of groundwater wells.
6. Farmers should be motivated to use good quality fertilizer to avoid further deuteriation of groundwater.
7. Public awareness regarding the sustainable use of groundwater should be initiated for the future sustainability of groundwater.

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Appendix A

Site Survey					
Well ID:		AK1	**Date:**		May 22, 2017
Local Well ID:		AD-D08-03753	**Time (HH:MM):**		9:03 AM
			Coordinates:		
Area	Al Khatim	√	E (DD-MM-SS):		55° 03' 33''
	Remah		N (DD-MM-SS):		24° 11' 17''
Farm No.:			Elevation		120 m
			Well Status		Operational
Type of Well		Borehole	√	**Well Operation(hr/d)**	6
		Dug Well		**Well Operation (d/wk)**	6
		Hybrid		**Riser Pipe Type & Dia (inch)**	12"
Water Supply:		Directly to farm	**Discharge Pipe Type & Dia (inch)**		12"
		To Reservoir	**Type of Pump**		Submersible
Well Status			**Type of Casing**		
Operational √			PVC √		Other
Disused			Steel		
Other			GRP		
			Casing Dia (inch): 12"		

Water Level Measurement:	
Datum Point Identification	Top of foundation
GL to Datum Point (m)	0.33
Water Level (m)	39.5
Well Depth (m)	97.54

Water Quality Measurement:		
EC & pH Measuring Point	End of Discharge Pipe	**EC (µS/cm) 22,000**
	By-pass Valve	
	Leaking drops of Discharge pipe	**pH 6.54**

Check List	
Water Samples	√
Pictures	√
Soil Sample	√
Other	-

Site Survey

Well ID:		AK2	**Date:**	May 22, 2017
Local Well ID:		AD-D08-52131	**Time (HH:MM):**	9:20 AM
			Coordinates:	
Area	Al Khatim	✓	E (DD-MM-SS):	55° 03' 16''
	Remah		N (DD-MM-SS):	24° 11' 26''
Farm No.:			Elevation	110 m
			Well Status	
Type of Well		Borehole ✓	**Well Operation(hr/d)**	6
		Dug Well	**Well Operation (d/wk)**	6
		Hybrid	**Riser Pipe Type & Dia (inch)**	12"
Water Supply:		Directly to farm	**Discharge Pipe Type & Dia (inch)**	12"
		To Reservoir	**Type of Pump**	Submersible
Well Status			**Type of Casing**	
Operational ✓			PVC ✓	Other
Disused			Steel	
Other			GRP	
			Casing Dia (inch): 14"	

Water Level Measurement:	
Datum Point Identification	Top of casing
GL to Datum Point (m)	0.56
Water Level (m)	37.98
Well Depth (m)	60.96

Water Quality Measurement:		
EC & pH Measuring Point	End of Discharge Pipe	**EC (µS/cm) 24,200**
	By-pass Valve	
	Leaking drops of Discharge pipe	**pH 7.03**

Check List	
Water Samples	✓
Pictures	✓
Soil Sample	✓
Other	-

Site Survey

Well ID:		AK3	**Date:**	May 22, 2017
Local Well ID:		AD-D08-53192	**Time (HH:MM):**	9:37 AM
			Coordinates:	
Area	Al Khatim	√	E (DD-MM-SS):	55° 02' 42''
	Remah		N (DD-MM-SS):	24° 11' 45''
Farm No.:			Elevation	110 m
			Well Status	

Type of Well		Borehole	√	**Well Operation(hr/d)**	6
		Dug Well		**Well Operation (d/wk)**	6
		Hybrid		**Riser Pipe Type & Dia (inch)**	12"
Water Supply:		Directly to farm		**Discharge Pipe Type & Dia (inch)**	12"
		To Reservoir		**Type of Pump**	Submersible

Well Status		**Type of Casing**	
Operational √		PVC	Other
Disused		Steel √	
Other		GRP	
		Casing Dia (inch): 12"	

Water Level Measurement:	
Datum Point Identification	Ground level
GL to Datum Point (m)	0
Water Level (m)	39.12
Well Depth (m)	146.3

Water Quality Measurement:		
EC & pH Measuring Point	End of Discharge Pipe	**EC (µS/cm) 19,700**
	By-pass Valve	
	Leaking drops of Discharge pipe	**pH 5.02**

Check List	
Water Samples	√
Pictures	√
Soil Sample	√
Other	-

Site Survey

Well ID:		AK4	**Date:**		May 22, 2017
Local Well ID:		AD-D08-53182	**Time (HH:MM):**		9:52 AM
			Coordinates:		
Area	Al Khatim	✓	E (DD-MM-SS):		55° 02' 37''
	Remah		N (DD-MM-SS):		24° 11' 46''
Farm No.:			Elevation		120 m
			Well Status		
Type of Well		Borehole	✓	**Well Operation(hr/d)**	6
		Dug Well		**Well Operation (d/wk)**	6
		Hybrid		**Riser Pipe Type & Dia (inch)**	12"
Water Supply:		Directly to farm	**Discharge Pipe Type & Dia (inch)**		12"
		To Reservoir	**Type of Pump**		Submersible
Well Status			**Type of Casing**		
Operational ✓			PVC		Other
Disused			Steel ✓		
Other			GRP		
			Casing Dia (inch): 12"		

Water Level Measurement:	
Datum Point Identification	Top of casing
GL to Datum Point (m)	0.26
Water Level (m)	41.81
Well Depth (m)	152.4

Water Quality Measurement:		
EC & pH Measuring Point	End of Discharge Pipe	**EC (µS/cm) 18,000**
	By-pass Valve	
	Leaking drops of Discharge pipe	**pH 6.09**

Check List	
Water Samples	✓
Pictures	✓
Soil Sample	✓
Other	-

<table>
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<tr><td colspan="2">Local Well ID:</td><td>AD-D08-53182</td><td colspan="2">Time (HH:MM):</td><td>10:05 AM</td></tr>
<tr><td colspan="3"></td><td colspan="3">Coordinates:</td></tr>
<tr><td>Area</td><td>Al Khatim</td><td>✓</td><td colspan="2">E (DD-MM-SS):</td><td>55° 02’ 11’’</td></tr>
<tr><td></td><td>Remah</td><td></td><td colspan="2">N (DD-MM-SS):</td><td>24° 11’ 54’’</td></tr>
<tr><td colspan="3" rowspan="2">Farm No.:</td><td colspan="2">Elevation</td><td>120 m</td></tr>
<tr><td colspan="2">Well Status</td><td></td></tr>
<tr><td>Type of Well</td><td></td><td>Borehole</td><td>✓</td><td>Well Operation(hr/d)</td><td>6</td></tr>
<tr><td colspan="2"></td><td>Dug Well</td><td></td><td>Well Operation (d/wk)</td><td>6</td></tr>
<tr><td colspan="2"></td><td>Hybrid</td><td></td><td>Riser Pipe Type & Dia (inch)</td><td>14”</td></tr>
<tr><td colspan="2">Water Supply:</td><td>Directly to farm</td><td colspan="2">Discharge Pipe Type & Dia (inch)</td><td>14”</td></tr>
<tr><td colspan="2"></td><td>To Reservoir</td><td colspan="2">Type of Pump</td><td>Submersible</td></tr>
<tr><td colspan="2">Well Status</td><td></td><td colspan="3">Type of Casing</td></tr>
<tr><td colspan="3">Operational ✓</td><td colspan="2">PVC</td><td rowspan="3">Other</td></tr>
<tr><td colspan="3">Disused</td><td colspan="2">Steel ✓</td></tr>
<tr><td colspan="3" rowspan="2">Other</td><td colspan="2">GRP</td></tr>
<tr><td colspan="3">Casing Dia (inch): 14”</td></tr>
<tr><td colspan="6">Water Level Measurement:</td></tr>
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<tr><td colspan="2">Water Level (m)</td><td colspan="4">42.55</td></tr>
<tr><td colspan="2">Well Depth (m)</td><td colspan="4">115.8</td></tr>
<tr><td colspan="6">Water Quality Measurement:</td></tr>
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<tr><td colspan="2"></td><td colspan="3">By-pass Valve</td></tr>
<tr><td colspan="2"></td><td colspan="3">Leaking drops of Discharge pipe</td><td rowspan="2">pH 5.52</td></tr>
<tr><td colspan="5"></td></tr>
<tr><td colspan="6">Check List</td></tr>
<tr><td colspan="2">Water Samples</td><td colspan="4">✓</td></tr>
<tr><td colspan="2">Pictures</td><td colspan="4">✓</td></tr>
<tr><td colspan="2">Soil Sample</td><td colspan="4">✓</td></tr>
<tr><td colspan="2">Other</td><td colspan="4">-</td></tr>
</table>

Site Survey

Well ID:		AK6	**Date:**		May 22, 2017
Local Well ID:		AD-D08-54001	**Time (HH:MM):**		10:23 AM
			Coordinates:		
Area	Al Khatim	✓	E (DD-MM-SS):		55° 02’ 27’’
	Remah		N (DD-MM-SS):		24° 12’ 21’’
Farm No.:			Elevation		110 m
			Well Status		Operational
Type of Well		Borehole		**Well Operation(hr/d)**	5
		Dug Well	✓	**Well Operation (d/wk)**	6
		Hybrid		**Riser Pipe Type & Dia (inch)**	3”
Water Supply:		Directly to farm	**Discharge Pipe Type & Dia (inch)**		3”
		To Reservoir	**Type of Pump**		Submersible
Well Status			**Type of Casing**		
Operational ✓			PVC		Other
Disused			Steel		
Other			GRP ✓		
			Casing Dia (inch): 44”		

Water Level Measurement:	
Datum Point Identification	Top of casing
GL to Datum Point (m)	1.05
Water Level (m)	23.6
Well Depth (m)	29.4

Water Quality Measurement:		
EC & pH Measuring Point	End of Discharge Pipe	**EC (µS/cm) 16,700**
	By-pass Valve	
	Leaking drops of Discharge pipe	**pH 6.03**

Check List	
Water Samples	✓
Pictures	✓
Soil Sample	✓
Other	-

Site Survey

Well ID:		AK7	**Date:**	May 22, 2017
Local Well ID:		AD-D08-60719	**Time (HH:MM):**	10:45 AM
			Coordinates:	
Area	Al Khatim	√	E (DD-MM-SS):	55° 02' 31''
	Remah		N (DD-MM-SS):	24° 12' 37''
Farm No.:			Elevation	100 m
			Well Status	
Type of Well		Borehole √	**Well Operation(hr/d)**	6
		Dug Well	**Well Operation (d/wk)**	6
		Hybrid	**Riser Pipe Type & Dia (inch)**	14"
Water Supply:		Directly to farm	**Discharge Pipe Type & Dia (inch)**	14"
		To Reservoir	**Type of Pump**	Submersible
Well Status			**Type of Casing**	
Operational √			PVC	Other
Disused			Steel √	
Other			GRP	
			Casing Dia (inch): 14"	

Water Level Measurement:	
Datum Point Identification	Top of casing
GL to Datum Point (m)	0.47
Water Level (m)	31.8
Well Depth (m)	134.1

Water Quality Measurement:		
EC & pH Measuring Point	End of Discharge Pipe	**EC (µS/cm) 20,100**
	By-pass Valve	
	Leaking drops of Discharge pipe	**pH 5.57**

Check List	
Water Samples	√
Pictures	√
Soil Sample	√
Other	-

Site Survey

Well ID:		AK8	**Date:**	May 22, 2017
Local Well ID:		N/A	**Time (HH:MM):**	11:00 AM
			Coordinates:	
Area	Al Khatim	✓	E (DD-MM-SS):	55° 02’ 24’’
	Remah		N (DD-MM-SS):	24° 12’ 45’’
Farm No.:			Elevation	100 m
			Well Status	
Type of Well		Borehole	**Well Operation(hr/d)**	3
		Dug Well ✓	**Well Operation (d/wk)**	6
		Hybrid	**Riser Pipe Type & Dia (inch)**	12”
Water Supply:		Directly to farm	**Discharge Pipe Type & Dia (inch)**	12”
		To Reservoir	**Type of Pump**	Submersible
Well Status			**Type of Casing**	
Operational ✓			PVC	Other
Disused			Steel	
Other			GRP ✓	
			Casing Dia (inch): 44”	

Water Level Measurement:	
Datum Point Identification	Top of casing
GL to Datum Point (m)	0.37
Water Level (m)	18.3
Well Depth (m)	20.1

Water Quality Measurement:		
EC & pH Measuring Point	End of Discharge Pipe	**EC (µS/cm) 17,100**
	By-pass Valve	
	Leaking drops of Discharge pipe	**pH 6.69**

Check List	
Water Samples	✓
Pictures	✓
Soil Sample	✓
Other	-

Site Survey

Well ID:		AK9	**Date:**		May 22, 2017
Local Well ID:		AD-D08-51015	**Time (HH:MM):**		11:36 AM
			Coordinates:		
Area	Al Khatim	✓	E (DD-MM-SS):		55° 02’ 04’’
	Remah		N (DD-MM-SS):		24° 12’ 35’’
Farm No.:			Elevation		100 m
			Well Status		
Type of Well		Borehole	✓	**Well Operation(hr/d)**	6
		Dug Well		**Well Operation (d/wk)**	6
		Hybrid		**Riser Pipe Type & Dia (inch)**	12”
Water Supply:		Directly to farm	**Discharge Pipe Type & Dia (inch)**		12”
		To Reservoir	**Type of Pump**		Submersible
Well Status			**Type of Casing**		
Operational ✓			PVC		Other
Disused			Steel ✓		
Other			GRP		
			Casing Dia (inch): 14”		

Water Level Measurement:	
Datum Point Identification	Top of casing
GL to Datum Point (m)	0.31
Water Level (m)	17.38
Well Depth (m)	121.9

Water Quality Measurement:		
EC & pH Measuring Point	End of Discharge Pipe	**EC (µS/cm) 19,600**
	By-pass Valve	
	Leaking drops of Discharge pipe	**pH 6.02**

Check List	
Water Samples	✓
Pictures	✓
Soil Sample	✓
Other	-

Site Survey

Well ID:		AK10	**Date:**		May 22, 2017
Local Well ID:		AD-D08-51000	**Time (HH:MM):**		11:44 AM
			Coordinates:		
Area	Al Khatim	√	E (DD-MM-SS):		55° 02’ 09’’
	Remah		N (DD-MM-SS):		24° 12’ 33’’
Farm No.:			Elevation		120 m
			Well Status		
Type of Well		Borehole	√	**Well Operation(hr/d)**	6
		Dug Well		**Well Operation (d/wk)**	6
		Hybrid		**Riser Pipe Type & Dia (inch)**	12”
Water Supply:		Directly to farm	**Discharge Pipe Type & Dia (inch)**		12”
		To Reservoir	**Type of Pump**		Submersible
Well Status			**Type of Casing**		
Operational √			PVC		Other
Disused			Steel √		
Other			GRP		
			Casing Dia (inch): 10”		

Water Level Measurement:	
Datum Point Identification	Top of casing
GL to Datum Point (m)	0.28
Water Level (m)	38.25
Well Depth (m)	130

Water Quality Measurement:		
EC & pH Measuring Point	End of Discharge Pipe	**EC (µS/cm) 22,300**
	By-pass Valve	
	Leaking drops of Discharge pipe	**pH 5.62**

Check List	
Water Samples	√
Pictures	√
Soil Sample	√
Other	-

Site Survey

Well ID:		R1	**Date:**	May 10, 2017
Local Well ID:		AD-D08-51510	**Time (HH:MM):**	8:50 AM
			Coordinates:	
Area	Al Khatim		E (DD-MM-SS):	55° 20’ 15’’
	Remah	√	N (DD-MM-SS):	24° 11’ 28’’
Farm No.:			Elevation	100 m
			Well Status	

Type of Well		Borehole	√	**Well Operation(hr/d)**	4
		Dug Well		**Well Operation (d/wk)**	5
		Hybrid		**Riser Pipe Type & Dia (inch)**	12”
Water Supply:		Directly to farm		**Discharge Pipe Type & Dia (inch)**	12”
		To Reservoir		**Type of Pump**	Submersible

Well Status		**Type of Casing**	
Operational √		PVC	Other
Disused		Steel √	
Other		GRP	
		Casing Dia (inch): 16”	

Water Level Measurement:	
Datum Point Identification	Top of casing
GL to Datum Point (m)	0.3
Water Level (m)	134.43
Well Depth (m)	168

Water Quality Measurement:		
EC & pH Measuring Point	End of Discharge Pipe	**EC (µS/cm) 7,260**
	By-pass Valve	
	Leaking drops of Discharge pipe	**pH 6.86**

Check List	
Water Samples	√
Pictures	√
Soil Sample	√
Other	-

Site Survey

Well ID:		R2	**Date:**		May 10, 2017
Local Well ID:		AD-D08-50549	**Time (HH:MM):**		9:08 AM
			Coordinates:		
Area	Al Khatim		E (DD-MM-SS):		55° 20' 26''
	Remah	✓	N (DD-MM-SS):		24° 11' 18''
Farm No.:			Elevation		160 m
			Well Status		
Type of Well		Borehole	✓	**Well Operation(hr/d)**	5
		Dug Well		**Well Operation (d/wk)**	5
		Hybrid		**Riser Pipe Type & Dia (inch)**	12"
Water Supply:		Directly to farm	**Discharge Pipe Type & Dia (inch)**		12"
		To Reservoir	**Type of Pump**		Submersible
Well Status			**Type of Casing**		
Operational ✓			PVC		Other
Disused			Steel ✓		
Other			GRP		
			Casing Dia (inch): 20"		

Water Level Measurement:	
Datum Point Identification	Top of casing
GL to Datum Point (m)	0.36 m
Water Level (m)	137.73
Well Depth (m)	198

Water Quality Measurement:		
EC & pH Measuring Point	End of Discharge Pipe	**EC (µS/cm) 6,950**
	By-pass Valve	
	Leaking drops of Discharge pipe	**pH 7.06**

Check List	
Water Samples	✓
Pictures	✓
Soil Sample	✓
Other	-

Site Survey

Well ID:		R3	**Date:**		May 10, 2017
Local Well ID:		AD-D08-50580	**Time (HH:MM):**		10:00 AM
			Coordinates:		
Area	Al Khatim		E (DD-MM-SS):		55° 20' 49''
	Remah	✓	N (DD-MM-SS):		24° 11' 50''
Farm No.:			Elevation		140 m
			Well Status		
Type of Well		Borehole	✓	**Well Operation(hr/d)**	6
		Dug Well		**Well Operation (d/wk)**	6
		Hybrid		**Riser Pipe Type & Dia (inch)**	12"
Water Supply:		Directly to farm	**Discharge Pipe Type & Dia (inch)**		12"
		To Reservoir	**Type of Pump**		Submersible
Well Status			**Type of Casing**		
Operational ✓			PVC		Other
Disused			Steel ✓		
Other			GRP		
			Casing Dia (inch): 15"		

Water Level Measurement:	
Datum Point Identification	Top of casing
GL to Datum Point (m)	0.32
Water Level (m)	145.91
Well Depth (m)	168

Water Quality Measurement:		
EC & pH Measuring Point	End of Discharge Pipe	**EC (µS/cm) 8.03**
	By-pass Valve	
	Leaking drops of Discharge pipe	**pH 7.16**

Check List	
Water Samples	✓
Pictures	✓
Soil Sample	✓
Other	-

Site Survey

Well ID:		R4	**Date:**		May 10, 2017
Local Well ID:		AD-D08-55074	**Time (HH:MM):**		10:38 AM
			Coordinates:		
Area	Al Khatim		E (DD-MM-SS):		55° 21’ 18’’
	Remah	√	N (DD-MM-SS):		24° 11’ 37’’
Farm No.:			Elevation		160 m
			Well Status		
Type of Well		Borehole	√	**Well Operation(hr/d)**	5
		Dug Well		**Well Operation (d/wk)**	6
		Hybrid		**Riser Pipe Type & Dia (inch)**	12”
Water Supply:		Directly to farm	**Discharge Pipe Type & Dia (inch)**		12”
		To Reservoir	**Type of Pump**		Submersible
Well Status			**Type of Casing**		
Operational √			PVC		Other
Disused			Steel √		
Other			GRP		
			Casing Dia (inch): 15”		

Water Level Measurement:	
Datum Point Identification	Top of casing
GL to Datum Point (m)	0.32
Water Level (m)	145.91
Well Depth (m)	304.8

Water Quality Measurement:		
EC & pH Measuring Point	End of Discharge Pipe	**EC (µS/cm) 7,570**
	By-pass Valve	
	Leaking drops of Discharge pipe	**pH 4.48**

Check List	
Water Samples	√
Pictures	√
Soil Sample	√
Other	-

Site Survey

Well ID:		R5	**Date:**		May 18, 2017
Local Well ID:		AD-D08-51585	**Time (HH:MM):**		7:30 AM
			Coordinates:		
Area	Al Khatim		E (DD-MM-SS):		55° 20’ 32’’
	Remah	√	N (DD-MM-SS):		24° 08’ 40’’
Farm No.:			Elevation		150 m
			Well Status		
Type of Well		Borehole	√	**Well Operation(hr/d)**	4
		Dug Well		**Well Operation (d/wk)**	5
		Hybrid		**Riser Pipe Type & Dia (inch)**	12”
Water Supply:		Directly to farm	**Discharge Pipe Type & Dia (inch)**		12”
		To Reservoir	**Type of Pump**		Submersible
Well Status			**Type of Casing**		
Operational √			PVC √		Other
Disused			Steel		
Other			GRP		
			Casing Dia (inch): 12”		

Water Level Measurement:	
Datum Point Identification	Top of casing
GL to Datum Point (m)	0.35
Water Level (m)	124.1
Well Depth (m)	243.8

Water Quality Measurement:		
EC & pH Measuring Point	End of Discharge Pipe	**EC (µS/cm) 5,130**
	By-pass Valve	
	Leaking drops of Discharge pipe	**pH 5.06**

Check List	
Water Samples	√
Pictures	√
Soil Sample	√
Other	-

Site Survey

Well ID:		R6	**Date:**		May 18, 2017
Local Well ID:		AD-D08-51590	**Time (HH:MM):**		7:55 AM
			Coordinates:		
Area	Al Khatim		E (DD-MM-SS):		55° 20’ 21’’
	Remah	✓	N (DD-MM-SS):		24° 08’ 43’’
Farm No.:			Elevation		150 m
			Well Status		
Type of Well		Borehole	✓	**Well Operation(hr/d)**	6
		Dug Well		**Well Operation (d/wk)**	6
		Hybrid		**Riser Pipe Type & Dia (inch)**	14”
Water Supply:		Directly to farm	**Discharge Pipe Type & Dia (inch)**		14”
		To Reservoir	**Type of Pump**		Submersible
Well Status			**Type of Casing**		
Operational ✓			PVC		Other
Disused			Steel ✓		
Other			GRP		
			Casing Dia (inch): 22”		

Water Level Measurement:	
Datum Point Identification	Top of casing
GL to Datum Point (m)	0.3
Water Level (m)	182.45
Well Depth (m)	168

Water Quality Measurement:		
EC & pH Measuring Point	End of Discharge Pipe	**EC (µS/cm) 5,890**
	By-pass Valve	
	Leaking drops of Discharge pipe	**pH 6.05**

Check List	
Water Samples	✓
Pictures	✓
Soil Sample	✓
Other	-

Site Survey

Well ID:		R7	**Date:**		May 18, 2017
Local Well ID:		AD-D08-50680	**Time (HH:MM):**		9:00 AM
			Coordinates:		
Area	Al Khatim		E (DD-MM-SS):		55° 19’ 59’’
	Remah	✓	N (DD-MM-SS):		24° 09’ 42’’
Farm No.:			Elevation		180 m
			Well Status		
Type of Well		Borehole	✓	**Well Operation(hr/d)**	6
		Dug Well		**Well Operation (d/wk)**	6
		Hybrid		**Riser Pipe Type & Dia (inch)**	12”
Water Supply:		Directly to farm	**Discharge Pipe Type & Dia (inch)**		12”
		To Reservoir	**Type of Pump**		Submersible
Well Status			**Type of Casing**		
Operational ✓			PVC		Other
Disused			Steel ✓		
Other			GRP		
			Casing Dia (inch): 14”		

Water Level Measurement:	
Datum Point Identification	Top of casing
GL to Datum Point (m)	0.38
Water Level (m)	102.9
Well Depth (m)	168

Water Quality Measurement:		
EC & pH Measuring Point	End of Discharge Pipe	**EC (µS/cm) 5,890**
	By-pass Valve	
	Leaking drops of Discharge pipe	**pH 6.05**

Check List	
Water Samples	✓
Pictures	✓
Soil Sample	✓
Other	-

Site Survey

Well ID:		R8	**Date:**	May 18, 2017
Local Well ID:		AD-D08-12332	**Time (HH:MM):**	9:42 AM
			Coordinates:	
Area	Al Khatim		E (DD-MM-SS):	55° 20' 49''
	Remah	✓	N (DD-MM-SS):	24° 09' 42''
Farm No.:			Elevation	160 m
			Well Status	
Type of Well		Borehole ✓	**Well Operation(hr/d)**	8
		Dug Well	**Well Operation (d/wk)**	6
		Hybrid	**Riser Pipe Type & Dia (inch)**	14"
Water Supply:		Directly to farm	**Discharge Pipe Type & Dia (inch)**	14"
		To Reservoir	**Type of Pump**	Submersible
Well Status			**Type of Casing**	
Operational ✓			PVC	Other
Disused			Steel ✓	
Other			GRP	
			Casing Dia (inch): 16"	

Water Level Measurement:	
Datum Point Identification	Top of casing
GL to Datum Point (m)	0.1
Water Level (m)	152.58
Well Depth (m)	366

Water Quality Measurement:		
EC & pH Measuring Point	End of Discharge Pipe	**EC (µS/cm) 5,110**
	By-pass Valve	
	Leaking drops of Discharge pipe	**pH 5.39**

Check List	
Water Samples	✓
Pictures	✓
Soil Sample	✓
Other	-

Site Survey

Well ID:		R9	**Date:**		May 18, 2017
Local Well ID:		AD-D08-02808	**Time (HH:MM):**		10:00 AM
			Coordinates:		
Area	Al Khatim		E (DD-MM-SS):		55° 20’ 52’’
	Remah	✓	N (DD-MM-SS):		24° 09’ 46’’
Farm No.:			Elevation		160 m
			Well Status		
Type of Well		Borehole	✓	**Well Operation(hr/d)**	5
		Dug Well		**Well Operation (d/wk)**	5
		Hybrid		**Riser Pipe Type & Dia (inch)**	12”
Water Supply:		Directly to farm	**Discharge Pipe Type & Dia (inch)**		12”
		To Reservoir	**Type of Pump**		Submersible
Well Status			**Type of Casing**		
Operational ✓			PVC		Other
Disused			Steel ✓		
Other			GRP		
			Casing Dia (inch): 10”		

Water Level Measurement:	
Datum Point Identification	Top of casing
GL to Datum Point (m)	0.53
Water Level (m)	198.51
Well Depth (m)	304.8

Water Quality Measurement:		
EC & pH Measuring Point	End of Discharge Pipe	**EC (µS/cm) 5,760**
	By-pass Valve	
	Leaking drops of Discharge pipe	**pH 6.18**

Check List	
Water Samples	✓
Pictures	✓
Soil Sample	✓
Other	-

Site Survey

Well ID:		R10	**Date:**		May 18, 2017
Local Well ID:		AD-D08-55628	**Time (HH:MM):**		10:25 AM
			Coordinates:		
Area	Al Khatim		E (DD-MM-SS):		55° 21’ 17’’
	Remah	✓	N (DD-MM-SS):		24° 09’ 39’’
Farm No.:			Elevation		150 m
			Well Status		
Type of Well		Borehole	✓	**Well Operation(hr/d)**	5
		Dug Well		**Well Operation (d/wk)**	6
		Hybrid		**Riser Pipe Type & Dia (inch)**	12”
Water Supply:		Directly to farm	**Discharge Pipe Type & Dia (inch)**		12”
		To Reservoir	**Type of Pump**		Submersible
Well Status			**Type of Casing**		
Operational ✓			PVC		Other
Disused			Steel ✓		
Other			GRP		
			Casing Dia (inch): 20”		

Water Level Measurement:	
Datum Point Identification	Top of casing
GL to Datum Point (m)	0.7
Water Level (m)	187.82
Well Depth (m)	243.84

Water Quality Measurement:		
EC & pH Measuring Point	End of Discharge Pipe	**EC (µS/cm) 4,710**
	By-pass Valve	
	Leaking drops of Discharge pipe	**pH 5.12**

Check List	
Water Samples	✓
Pictures	✓
Soil Sample	✓
Other	-

Appendix B

Well ID	Geog. Coordinates E	Geog. Coordinates N	Water Level BGL (m)	Well Depth (m)	EC (mS/cm)	Salinity (ppm)	pH	Temp (°C)	Na^+ (ppm)	Ca^{2+} (ppm)	Mg^{2+} (ppm)	K^+ (ppm)	Cl^- (ppm)	SO_4^{2-} (ppm)	HCO_3^- (ppm)	NO_3^- (ppm)	Cd (ppm)	Zn (ppm)	Cr (ppm)	Pb (ppm)	TDS (ppm)
Remah																					
R1	55° 20' 15''	24° 11' 28''	134.4	168	7.26	4,000	6.9	30.7	872.8	188	47.3	14.3	1,474	1,715	32.1	20.8	0.96	0.01	0.005	<0.01	4,864
R2	55° 20' 26''	24° 11' 18''	137.7	198	6.95	3,800	7.1	33.8	812.5	171	30.2	13	1,383	1,539	34.7	28.8	0.72	0.01	0.004	<0.01	4,656
R3	55° 20' 49''	24° 11' 50''	145.9	168	8.03	4,400	7.2	32.3	790.8	242	43	26.6	1,242	2,016	48.2	45.1	0.46	0.01	0.006	<0.01	5,380
R4	55° 21' 18''	24° 11' 37''	124.1	304.8	7.57	4,200	4.5	34.5	684.4	185	29.1	24.5	1,184	2,003	50.6	80.9	0.8	0.01	0.006	<0.01	5,072
R5	55° 20' 32''	24° 08' 40''	182.5	243.8	5.13	2,700	5.1	35.2	655.5	187	27.4	10.2	1,036	1,205	35.8	29.3	0.45	0.01	0.006	<0.01	3,437
R6	55° 20' 21''	24° 08' 43''	102.9	168	5.89	3,200	6.1	35	610.5	90	23.6	18.9	8,63.8	1,544	37.1	139	0.72	0.01	0.005	<0.01	3,946
R7	55° 19' 59''	24° 09' 42''	152.6	213.4	5.5	2,900	5.3	34.9	680.8	66.2	24.7	10.3	9,87.8	1,356	45.4	155	2.2	0.01	0.005	<0.01	3,685
R8	55° 20' 49''	24° 09' 42''	198.5	366	5.11	2,700	5.4	37.6	580.8	84	21.6	10	850.5	1,288	36.1	164	0.94	0.01	0.006	<0.01	3,424
R9	55° 20' 52''	24° 09' 46''	192.3	304.8	5.76	3,100	6.2	37.3	680.8	93.6	24.7	16.2	1,244	1,318	37.2	139	0.32	0.01	0.005	<0.01	3,859
R10	55° 21' 17''	24° 09' 39''	187.8	243.8	4.71	2,500	5.1	34.3	580.8	61.8	20.5	6.2	890.9	1,143	35.8	163	0.25	0.01	0.005	<0.01	3,156
Al Khatim																					
AK1	55° 03' 33''	24° 11' 17''	39.5	97.5	22	13,200	6.5	31.3	2,865	592	181	37.6	5,529	3,673	80	57	0.75	0.01	0.005	<0.01	12,165
AK2	55° 03' 16''	24° 11' 26''	37.9	60.9	24.2	14,600	7	30.6	2,786	542	183	48.4	5,888	5,457	127	126	0.996	0.01	0.006	<0.01	14,371
AK3	55° 02' 42''	24° 11' 45''	39.1	146.3	19.7	11,700	5	30.9	2,321	679	113	34.2	4,811	3,578	107	175	0.65	0.01	0.006	<0.01	10,876
AK4	55° 02' 37''	24° 11' 46''	41.8	152.4	18	10,600	6.1	31.5	2,148	672	89	16.8	4,094	3,500	93	347	0.05	0.01	0.005	<0.01	9,702
AK5	55° 02' 11''	24° 11' 54''	42.6	115.8	18.7	11,100	5.5	31.1	2,307	655	93	12.4	4,182	2,827	96	54	0.33	0.01	0.006	<0.01	9,006
AK6	55° 02' 27''	24° 12' 21''	23.6	29.4	16.7	9,700	6	33.4	2,047	436	112	13.2	4,094	3,441	93	347	0.08	0.01	0.006	<0.01	9,645
AK7	55° 02' 31''	24° 12' 37''	31.8	134.1	20.1	11,800	5.6	32	2,388	819	114	18	4,711	2,827	115	522	0.95	0.01	0.005	<0.01	10,262
AK8	55° 02' 24''	24° 12' 45''	18.3	20.1	17.1	10,000	6.7	31.9	2,517	677	93	37.4	4,152	5,096	84	14	0.08	0.01	0.005	<0.01	11,316
AK9	55° 02' 04''	24° 12' 35''	17.4	121.9	19.6	11,600	6	30.6	2,383	759	106	18.7	4,411	3,094	108	455	0.26	0.01	0.005	<0.01	10,375
AK10	55° 02' 09''	24° 12' 33''	38.3	130	22.3	13,400	5.6	33.1	2,765	1,007	163	37	5,427	2,827	140	1060	0.25	0.01	0.006	<0.01	11,209

Appendix C

Remah									
Well ID	**Geog. Coordinates**		**Ground elevation from sea level (m)**	**EC (µS/cm)**	**pH**	**Temp (°C)**	**Measured Radon 40mL (^{222}Rn Bq/L) [L/100]**	**Calculated ^{222}Rn at the sampling time**	**TDS (ppm)**
	E	**N**							
R1	55° 19' 25"	24° 11' 10"	511	5,940	8.35	34.2	3.7	4.0	2,966
R2	55° 15' 0"	24° 7' 13"	522	7,670	7.79	34.7	3.08	3.2	5,369
R3	55° 20' 22"	24° 8' 37"	546	4,990	7.76	35	9.84	10.0	3,493
R4	55° 21' 25"	24° 11' 59"	499	6,107	7.57	35.28	7	7.2	3,067
R5	55° 19' 43"	24° 12' 18"	503	7,640	7.45	33	7.2	7.4	3,821
R6	55° 19' 59"	24° 9' 46"	530	3,770	7.65	37.6	8.65	8.9	1,888
R7	55° 17' 4"	24° 10' 37"	430	5,240	7.8	31.8	2.46	2.6	2,430
R8	55° 15' 17"	24° 11' 11"	507	7,010	7.49	31.1	7.82	8.1	3,330
R9	55° 18' 8"	24° 8' 48"	517	5,200	7.67	34.2	14.2	14.6	2,290

Al Khatim-Al Khaznah									
Well ID	**Geog. Coordinates**		**Ground elevation from sea level (m)**	**EC (µS/cm)**	**pH**	**Temp (°C)**	**Measured Radon 40mL (^{222}Rn Bq/L) [L/100]**	**Calculated ^{222}Rn at the sampling time**	**TDS (ppm)**
	E	**N**							
AK1	55° 0' 19"	24° 12' 35"	345	21,090	7.24	29.8	24.5	25.2	14,763
AK2	55° 3' 59"	24° 12' 45"	400	13,040	7.46	30.7	23.5	24.1	9,128
AK3	55° 7' 25"	24° 11' 4"	408	14,190	7.32	30.3	15.7	16.0	9,933
AK4	55° 10' 58"	24° 11' 19"	449	7,700	7.8	30.4	9.23	9.3	5,390
AK5	55° 5' 43"	24° 12' 50"	406	16,860	7.35	28.9	3.48	3.5	11,800
AK6	55° 5' 26"	24° 15' 12"	354	16,960	7.29	30.4	9.386	9.6	11,872
AK7	55° 2' 26"	24° 11' 41"	137	19,240	7.46	33.5	17.2	18.0	9,270
AK8	55° 2' 58"	24° 12' 8"	286	17,920	7.42	32.9	9.89	10.4	8,720
AK9	55° 0' 4"	24° 15' 52"	299	18,250	7.11	30.5	4.73	4.9	9,350
AK10	55° 1' 18"	24° 15' 26"	319	7,880	7.53	31.3	3.69	3.8	3,730
AK11	54° 57' 33"	24° 13' 24"	298	13,300	7.4	29.5	3.48	3.6	6,750
AK12	54° 59' 1"	24° 11' 59"	251	24,000	7.32	31.3	2.46	2.6	12,350
AK13	54° 59' 51"	24° 11' 51"	160	25,400	7.18	29.2	1.44	1.5	13,860
AK14	54° 59' 16"	24° 12' 42"	376	21,990	7.36	29.5	1.64	1.7	11,620
AK15	55° 6' 38"	24° 9' 12"	375	15,700	7.37	31.6	8.43	8.9	7,850
AK16	54° 59' 28"	24° 11' 11"	316	8,310	7.13	31	3.48	3.7	4,010
AK17	55° 0' 39"	24° 11' 13"	330	37,100	7.51	31.6	1.64	1.7	19,800
AK18	55° 1' 24"	24° 10' 59"	335	31,100	7.16	30.9	9.45	9.7	16,750
AK19	55° 2' 4"	24° 10' 18"	321	19,090	7.99	29.9	2.05	2.1	10,540
AK20	55° 8' 44"	24° 10' 12"	442	13,300	7.38	29.9	28	30.9	6,690
AK21	55° 10' 1"	24° 10' 28"	436	10,770	7.71	31.4	4.52	4.5	5,260
AK22	55° 10' 23"	24° 10' 49"	422	18,400	7.41	31.3	0.821	0.8	9,290
AK23	55° 7' 19"	24° 10' 3"	418	17,180	7.51	32.2	6.98	7.2	8,470