REPUPLIC OF YEMEN

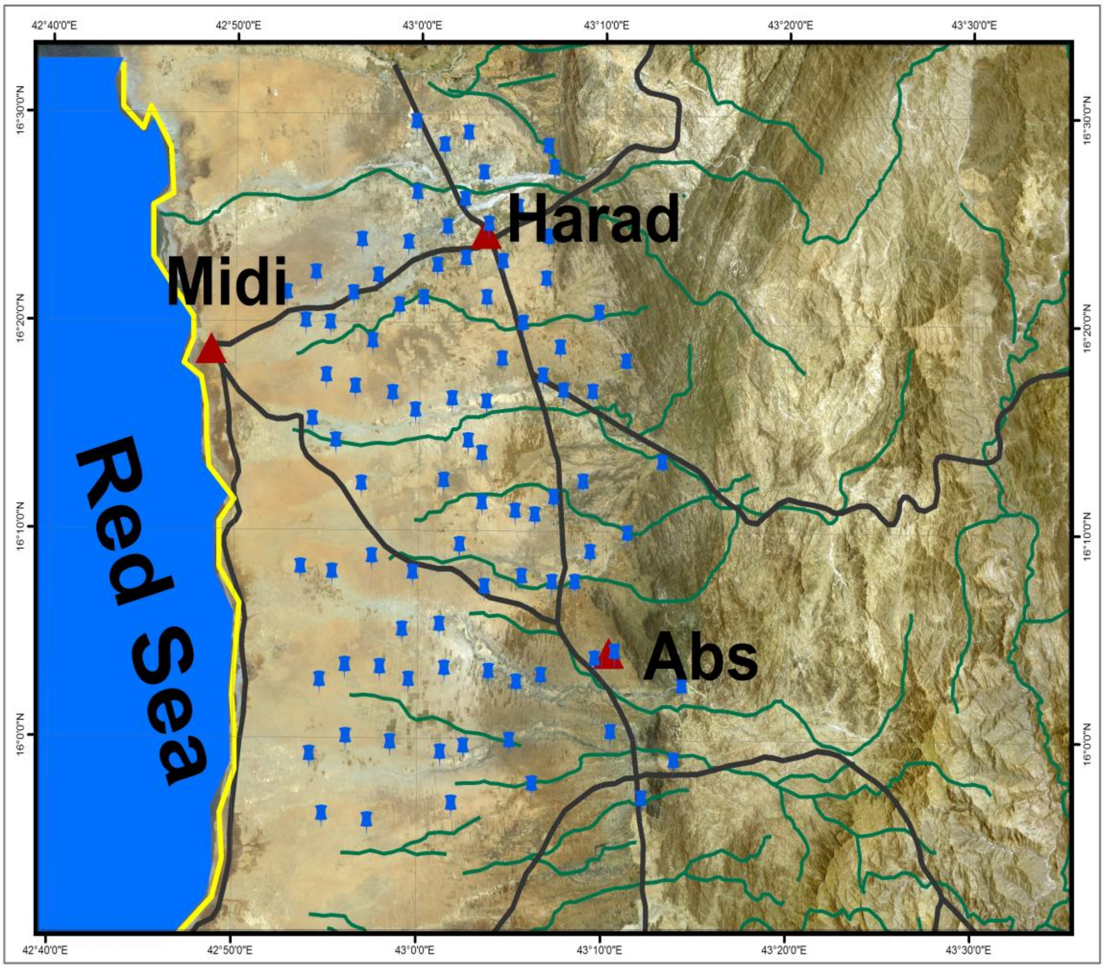
Ministry Of Water and Environment

National Water Resource Authority

Studies and Planning Sector

TIHAMA WATER RESOURCES MANAGEMENT

# Wadi Harad and Al Jar Water Quality



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## Acknowledgement

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# ABSTRACT

Ninety one groundwater samples were collected from Wadi Harad and Al Jar catchment area for hydrogeochemical investigations to understand the hydrogeochemical processes affecting groundwater chemistry and their relation with groundwater quality. Groundwater in the study area is abstracted from different aquifers. The study area is characterized by arid climate and extremely high relative humidity .

The results indicate that groundwater in the study area is fresh to brackish in nature. The abundance of the major ions is as follows: Na+1 > Ca+2 > Mg+2 > K+1 and Cl-1 > HCO3-1 > SO4-2 > NO3-1. The hydrochemical investigation indicates that groundwater in the study area is significantly modified as groundwater moves from the east (recharge areas) to the west. The water type evolve from low TDS, earth alkaline water with increased portions of alkalis with prevailing bicarbonate in the recharge areas to moderate and high TDS, alkaline water with prevailing sulfate and chloride along Red Sea coast in the western parts. The prevailing hydrogeochemical processes operating in the study area are dissolution, mixing, evaporation, ion exchange and weathering of silicate minerals in the eastern part. The reverse ion exchange and sea water intrusion controls the groundwater chemistry along the Red Sea coast areas and few parts of the study area. Deterioration in groundwater quality from anthropogenic activities has resulted from saltwater intrusion along the coastal areas due to groundwater over pumping and extensive use of fertilizers. Salinity and nitrate contamination are the two major problems in the area, which is alarming considering the use of this water for drinking.

Keywords: Groundwater. Hydrogeochemical processes . Saltwater intrusion. Wadi Harad and Al Jar Yemen.

# 1 - Background to the study area

## 1-1 Introduction:

Water is the most important natural resources at all as it has qualities that no other covering water three-quarters of the globe as a key factor underlying the human life and all its social and economic development in various fields, particularly in the field of agriculture and industry (El Nagawy, 2000).

The problem of water in Yemen is not limited to falling water levels and scarcity, but extends to the quality of those waters, and a decline in their properties, and their retreat to the water unfit for use in all areas, especially in human use, especially when over-exploitation of those waters.

In view of the faces of the Republic of Yemen to the complex challenges of water and stood in the way of sustainable development due to its location in the Hotel subtropics, as well as the obvious imbalance of water resources in rain-fed, they were compelled to rely entirely on groundwater stocks. (Hababi, 2008).

The ability of the total amount of surface water in Yemen by (1000) million cubic meters of groundwater by (1500) million cubic meters at a total capacity of (2500) million cubic meters, but the different uses in a year (2000) were as follows: domestic water ( 238) million cubic meters and Agriculture (3094) million cubic meters, industry and others (68) million cubic meters total capacity (3400) million cubic meters, this means that there is a deficit of (900) million cubic meters (Ariqi, 2006).

The study of water quality for any given area or water basin of the most important work that must be done in order to make an assessment of water resources in that area because the presence of polluted water in the basin means not to take advantage of the pelvis and this spirit will be a study to assess the quality of water for areas of northern Tihama within an assessment of all water sources in the Tihama Plain, which until now included the study of water quality in each security wadis Rema, Zabid, Surdud, Siham, as in this study of Wadi Mawr, Hiran Wadi (Al Jar) and Wadi Harad.

## 1-2 The objectives of the study

The main objective and direct this study is to investigate the variables of quality of groundwater to gain access to an integrated assessment of an important requirement and the level of the basin as a whole.

This assessment is an important requirement for knowledge of the following points:

- Range of variations in the salinity of water in the tub.
- Types of pollutants in natural water basin
- Types of aquifers in the basin
- The extent to which pollution of the basin.
- Foundations for structural monitoring program and water quality monitoring

  Any plan of an adult aiming to manage water resources in the basin and protect it from pollution must begin with the dimensions and the translation of the points mentioned, and which also constitute a base for public awareness of local causes and risk of contamination of groundwater and the importance of the rationalization of water use and protection from depletion and pollution which will lead to strengthening the partnership of the community Associations contribute to strengthening the management of these resources and defending it.

## 1-3 Location of the Study Area:

The area is located north of the valuable traction Valley Mawr Between latitudes- 160 1600 North and longitudes 4300 - 4256 The east, covering an area of km ² / 100 east and traction region depends on irrigation from to about groundwater 7.000 hectares and permeates the Al Jar ,Bohal and Al Qur wadis and some small wadis.

The valleys of the drainage area of about traction combined 33 million \ M ³ Year. While the conduct of the valley Mawr 122 million \ M ³ and Wadi Harad 28.6 million \ M ³ Where away 48 Miles north of A Jar.

Starch in the Wadi Al Jar agricultural activity since the start of the eighties and the expansion of this agricultural activity significantly in the early nineties when it was the establishment of the agricultural cooperative association Al Jar and that the multiplicity of its activities and expanded considerably in recent years.

While the total area of Wadi Harad 1700 kilometers square, the Hiran Wadi880 kilometers square, Wadi  AlQur 243 square kilometers, the valley of Bohal 250 square kilometers and Wadi Bani nasher of 127 square kilometers.

The study area includes a large part of the Directorate of Abs , Harad and Midi directorates.

The total number of population in the study area is 328774 people, according to population and housing census in 2004.

Al Jar area is located within the Tihama Plain under the influence of tropical climate is hot summers and mild winters and an average temperature of 35 degrees Celsius and temperatures in the summer to 45 degrees Celsius. The average annual rainfall of 50 at the western side of the Red Sea coast up to 250 mm in the east of the area, and rainfall during the period from August to September, as the estimated rate of rainfall in the upper reaches of the valleys of the main feeding area traction directly (Bohal, AlQur, Hiran , Hubail bin nasher) estimated 300 mm The basin valleys adjacent to the traction area (Wadi Harad, Wadi Mawr) is up rates of rainfall of 350-450 mm / year.

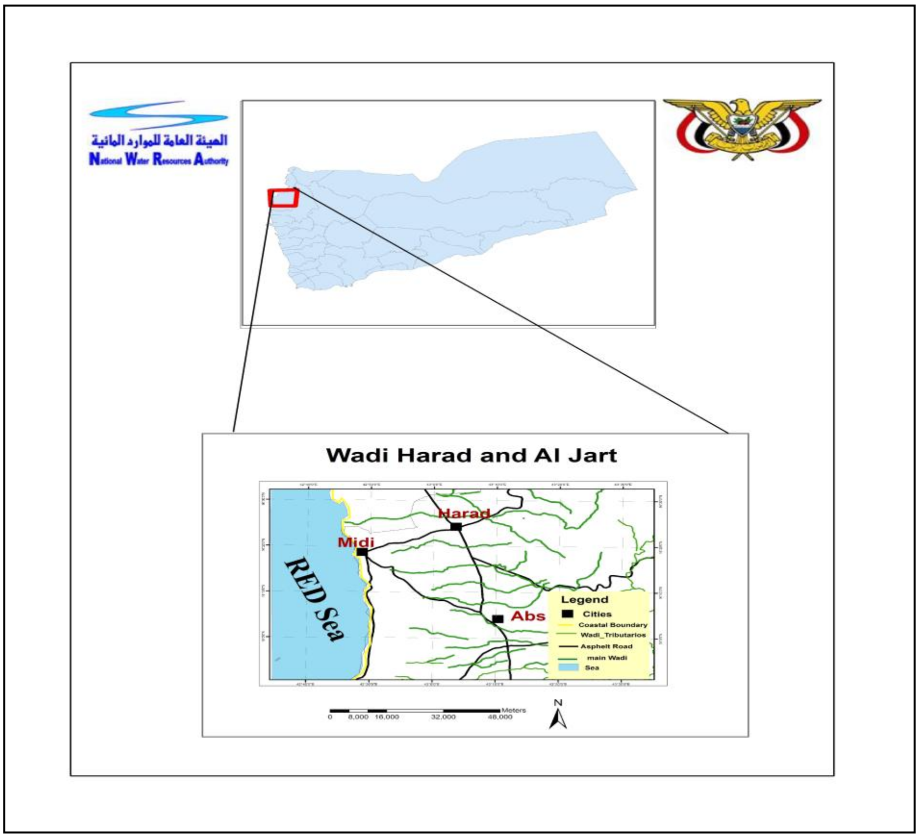


Figure 1: Location map of the study area.

## 1-4 Geology

### Wadi Harad and Al Jar

The traction area geology and topography of part of the Tihama plain, which contains the configurations:

Sediments of the Quaternary, which is in the layers of sediment containing fresh water thickness ranges from 50-200 meters and toward the South - North (the study of water resources in the Tihama DHV-1988) and because of the disparity in thickness of the layers to the presence of faults and fractures parallel to the Red Sea, also included in this sediment sediment valleys such as pitted, Moore, Cor, mud, Hiran and parts of the Delta are chiefly on the composition of the gravel and stones in the highest, and mud and sand in the bottom and the thickness ranges from 20-50 meters underground reservoirs composed along these valleys. It consists of layers of salt marshes and sandy clay deposits and extends freely along the Red Sea coast and contains at salt water.

- Tertiary formations (volcanic rock)
- Configurations for the Jurassic and Cretaceous (rock Imran Kahlah)
- The basement.

The Tihama plain as a result of movements of tectonic and Alanksarriet ground that accompanied the formation of the Red Sea and extends Tehama plain along the Red Sea coast and its width is estimated at 40-60 km and a Tehama plain low was fill it with rocks and volcanic sediment mud, gravel and sand by Wadis sloping from the mountains consists of fertile agricultural lands. Basal rocks consist of volcanic rocks and ancient sedimentary rocks, metamorphic and sedimentary rocks extends under the modern in the region, and appear above the Earth's surface is composed Mountains are Melhan and Al jmema.

The limestone rocks Amran has formed beneath the surface of the sea and appear in the conservative argument and Upper Wadi Surdud and Mawr. As they appear volcanic rocks in the south east of the region consists Hufash Mountains and stretches along the western edge of the mountainous region and features Faults intensive.

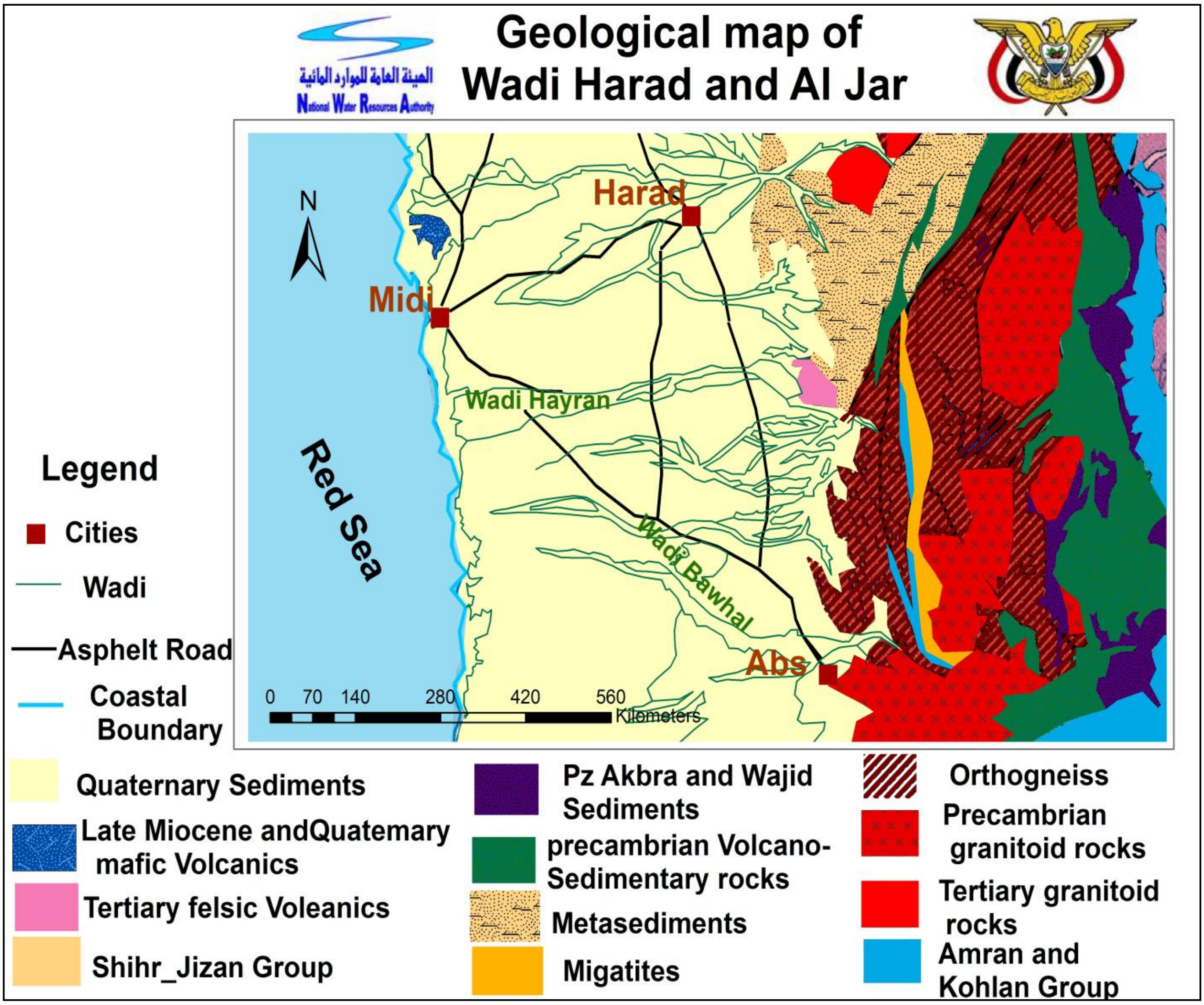


Figure2: Geological map of Wadi Haradh and Jar

# 2- Hydrochemical Study

## 2-1 Introduction

This study has been carried out for evaluation of the water resources in Wadi Mawr and Wadi Harad as part of the integrated water resources management in Wadi Mawr and Noth Tihama Basin. The study has investigated the quality of groundwater resources of Tihama Basin, and discusses the causes behind their current degradation trends. The study provides useful tools to predict the future outlook water quality in the region. In case measures are not taken to monitor and counteract the contaminating sources ,be highlighted on the different types of pollutants, possible sources and impacts on the ground water resources.

## 2-2 Specific objectives of the study

The specific objectives of the study are summarized as follows:

1. Update and obtain information about the hydrogeochemical properties of the main water bearing strata
2. Investigate the origin and spatial spread of brackish and saline waters
3. Groundwater quality in relation to use

## 2-3 Work carried out in Wadi Harad and Al Jar

To achieve the objectives of the study, the six fundamental survey preparation and field research activities were carried out which are summarized below:

- Review of the previous hydro- and geo-chemical information
- Selection of representative water-points for sample collection
- Specification of the sampling procedures
- Collection of groundwater samples
- Analysis in the field and in the laboratory and
- Data analysis and interpretation as a basis to formulate recommendations.

The six activities have been implemented in three sequential stages:

- Preparation work (2-3-1)
- Field Implementation (2-3-2) and
- Analysis & Data Processing ( 2-3-3)

## *2-3-1 Preparation work*

**2-3-1-1 Review and quality-check of available hydro- and geo-chemical data**

To check groundwater quality in a given area, it is necessary to gain a good knowledge about the conditions of water permanence and movement inside the targeted aquifers. As a first step, therefore, the present study has reviewed all the available records and studies related to the hydro-geological structure of Wadi Harad and Al Jar.

**2-3-1-2 Selection of water-points for water sample collection**

For sample collection purposes, there are many criteria to selection water points for water sample collection, including:

The water point should be at operational status according to the last well inventory (The results of the well inventory carried out by NWRA for The Wadi was in 2010).

1. There is information on pump depth and total depth for water points
2. The spatial distribution for samples from the Wadi
3. There is information on the geological structure for water points
4. There is advice from the well inventory survey

The selected wells for the study included both drilled boreholes fed by deep aquifers and hand-dug wells tapping shallow aquifers.

Hand-dug wells are very interesting from the water chemistry point of view, because they allow checking if pollution is occurring. Shallow aquifer pollution usually stems from human activities, particularly from used waters and other effluents, not suitably treated before disposal in the environment. The investigation of shallow aquifers allows identifying pollution sources, first in the shallow strata and, secondly, in the deeper ones. In fact, if the upper aquifer is polluted, the deeper one is likely to be polluted as well.

## *2-3-2 Field Implementation*

**2-3-2-1. Sampling and laboratory analysis**

The chemistry survey team for this project ( Appendix 1) was based in Al Qanawis and Harad , where the field leader was responsible for managing the daily collection of groundwater samples and supervising the laboratory analysis in NWRA, Sana'a Branch . The team started fieldwork on December 19, 2010 and ended it on February 16, 2011.

**2-3-2-2 Sample Collection**

In total, 200 samples were collected 107 from Wadi Mawr and 93 from Wadi Haradh (3 samples were duplicates) Annex (II). These wells including 32 dug wells (16%), 137 dug /boreholes (68.5 %), 28 boreholes (14% ) and 3 blank (1.5%). Sample locations and all characteristic are shown in Tables1

Table 1 : Types of samples collected wells

| Wadi | Dug | Borehole | Dug/Bore | Blank | Total |
|---|---|---|---|---|---|
| Harad and Al jar | 15 | 68 | 8 | 2 | 93 |

During sampling, the well owner was asked for any further information about the well, especially regarding the litho logy, pump depth and the location of screens. Field parameters measured at the well site were included in the field data sheet, a summary of collected and measured information is given in Appendix(2).

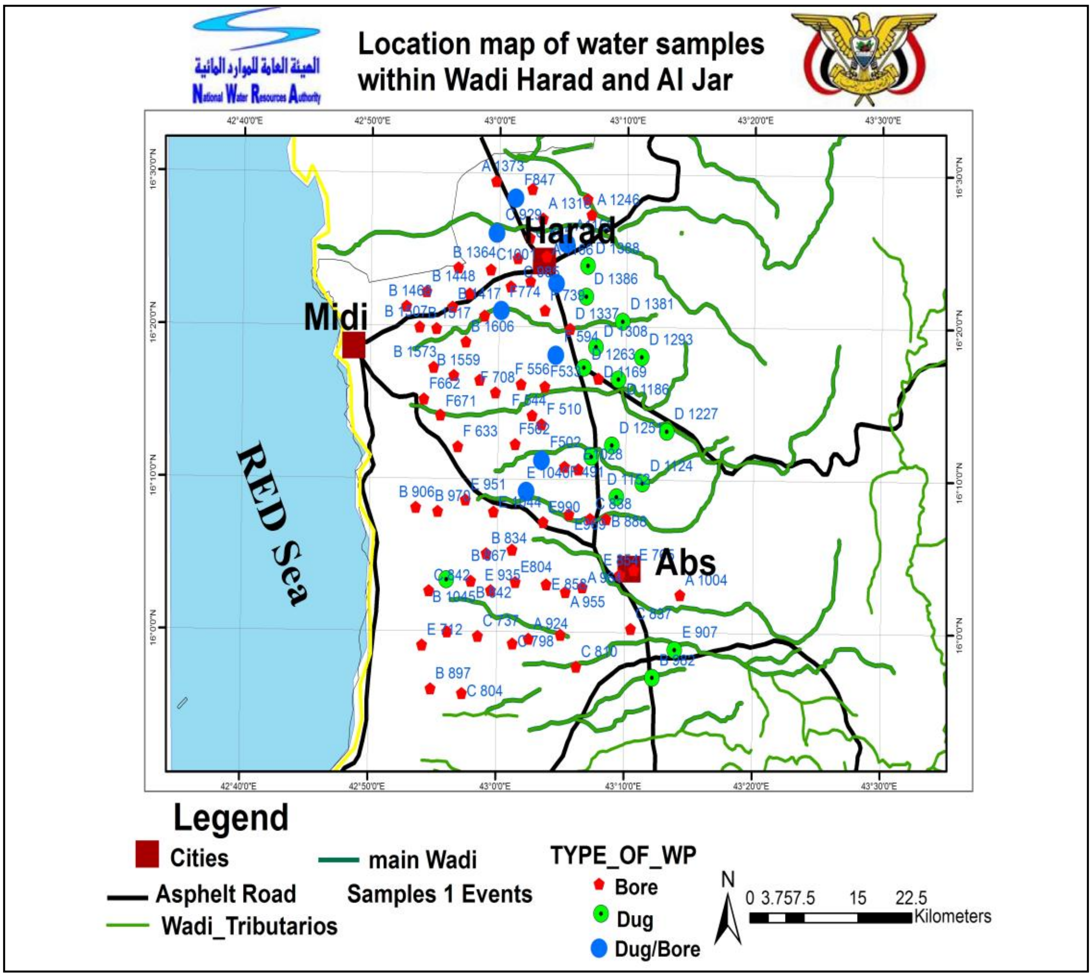


Figure 3: Location map of water samples within Wadi Harad and Al Jar

The operational wells were selected. The sample was collected after 30 minutes of pumping the well.

Samples were taken in clean, new polythene 1000-2000 ml bottles. At the site, the bottles were rinsed using the water being collected. Then the bottles were filled with water so that there was no air left in the bottles. In case of a closed irrigation well connected with a pipeline system, the outlet was chosen as close to the well as possible to decrease the influence of warming by the sun.

Labels were written on thick card with indelible pen, recording the time, date, sample location, sample number and analysis type, and attached securely to the sealed bottles.

The groundwater samples were stored in cool boxes while being transported to Sana'a, where they were analysed for EC and pH on the same day while other parameters were analysed the next day.

### 2-3-2-3 **Field difficulties**

The fieldwork of the water quality study team was hampered by two difficulties: the first was the discovery that the some wells that were operational during the last well inventory (2010-2011) had gone dry, so the well was substituted with another one. The second problem was that in some cases the pump was out of order. The non operational wells were thus re-visited after repair.

### 2-3-2-4 Measurement of field parameters

The purpose of making measurements in the field is for convenient rapid assessment and to provide control for laboratory measurements. The latter is important as the physical conditions of a sample may change between the time of sampling and the laboratory measurements. The parameters measured in the field were, electrical conductivity, pH, DO, and temperature.

**<u>Electrical conductivity (EC):</u>**

The electrical conductivity (EC) is a measure of the total salt content of water based on the flow of electrical current through the sample. The higher the salt content, the greater the flow of electrical current. EC is the reciprocal of resistively ( R ) and is reported in mS/cm or µS/cm.

Since the EC and TDS are measurements of the total salt content, they must be directly proportional.

The correlation between these two parameters for the analyzed samples in this study was plotted in Figure , which demonstrated a linear correlation with a mathematical. approximation of (TDS mg/L = 0.56 EC µS/cm). There were no measurements or analysis for the TDS during this study, therefore it was calculated using the equation of Freeze and Cherry (1979):

TDS mg/L = Ca+2 Mg+2 + Na+ + K+ + SO4-2- + NO3 -+0.5 HCO3  (all in mg/L)

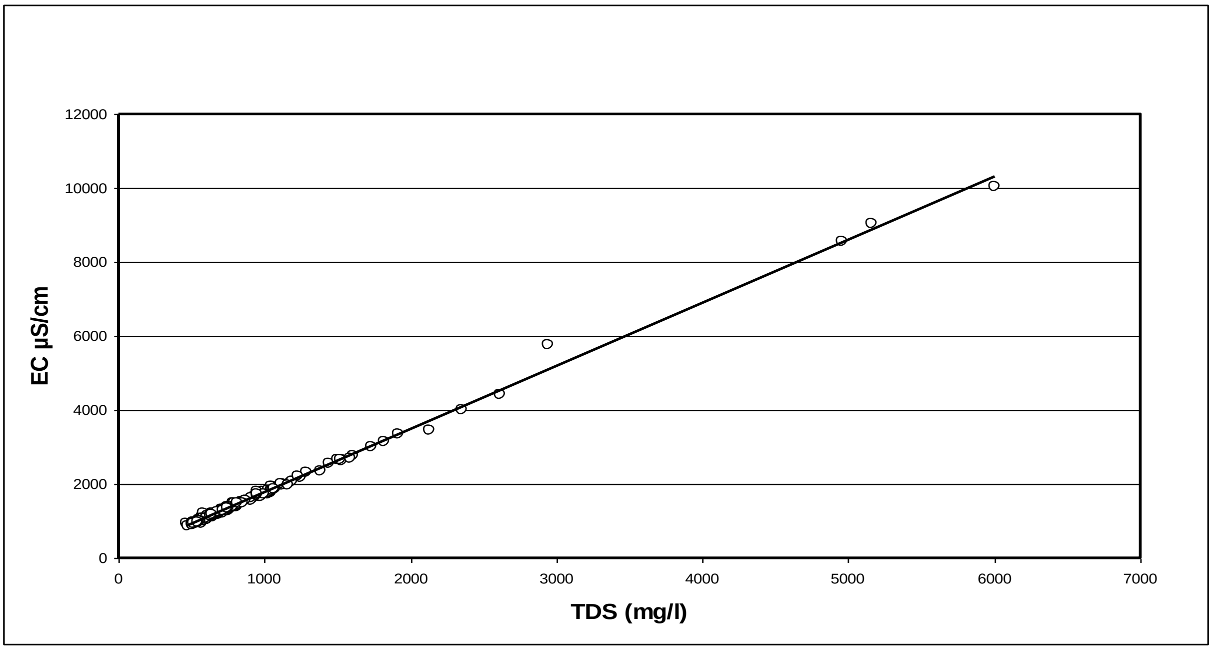


Figure 4: The relation between the EC and the TDS values in the study area

EC varied between 438µS/cm and 9990µS/cm in Wadi Harad and Al  Jar with an average of 2018 µS/cm. This indicated that the salinity of the water in Wadi Mawr is  higher than in Wadi Haradh and Jar.

The field investigation indicated that the major part of the Wadi Harad and Al Jar plain in quaternary aquifer system is fresh water excepting the western part, which outlined to the west of Midi  and west Al Jar  where the fresh water overlain by shallow brackish groundwater.

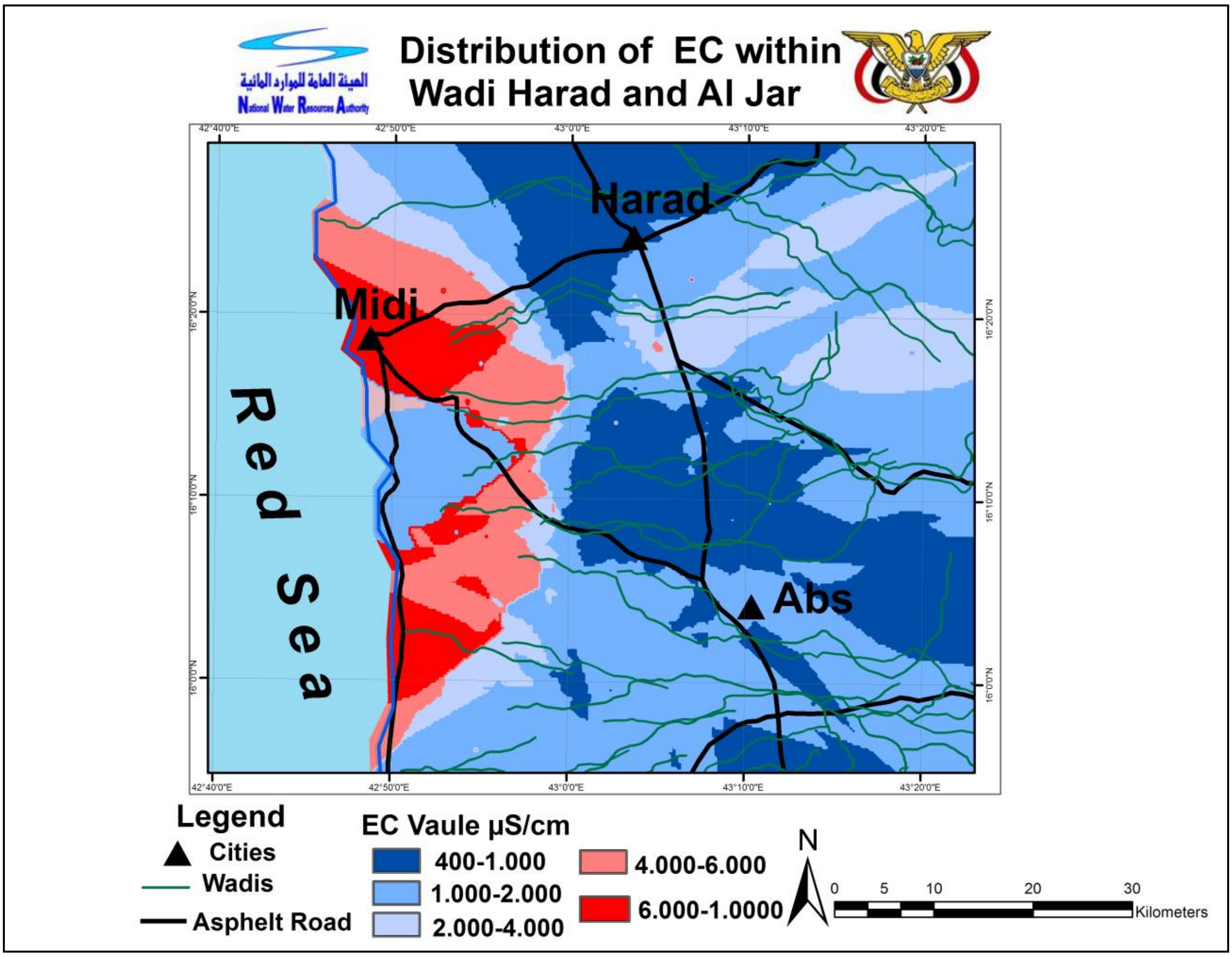


Figure 5: Distribution of Electrical Conductivity within Wadi Harad and Al Jar

**<u>Hydrogen - Ion Concentration (pH):</u>**

pH is defined as the negative logarithm to the base 10 of the hydrogen ion with the full pH scale ranging from 1-14.

If the pH value at 25C is 7, this means natural water. An excess of hydrogen (H+) indicated an acid water with corresponding pH value lower than 7. Conversely, an excess of hydroxyl ion (OH-) indicates alkaline water which has a pH value greater than 7. The measured pH is an important parameter in the geochemical equilibrium. The degree of precision of pH measurements, however, requires attention to electrode maintenance, buffer solutions, and temperature corrections.

In Harad and Jar the pH values of groundwater samples range from 6.88 to 8.2 with an average value 7.4. This shows that the groundwater in the study area is mainly an alkaline in nature pH varied between 6.4 and 8.8 with an average of 7.56.

Figure 6 clearly illustrates the pH values in Wadi Harad and Al Jar, which is normal in all area

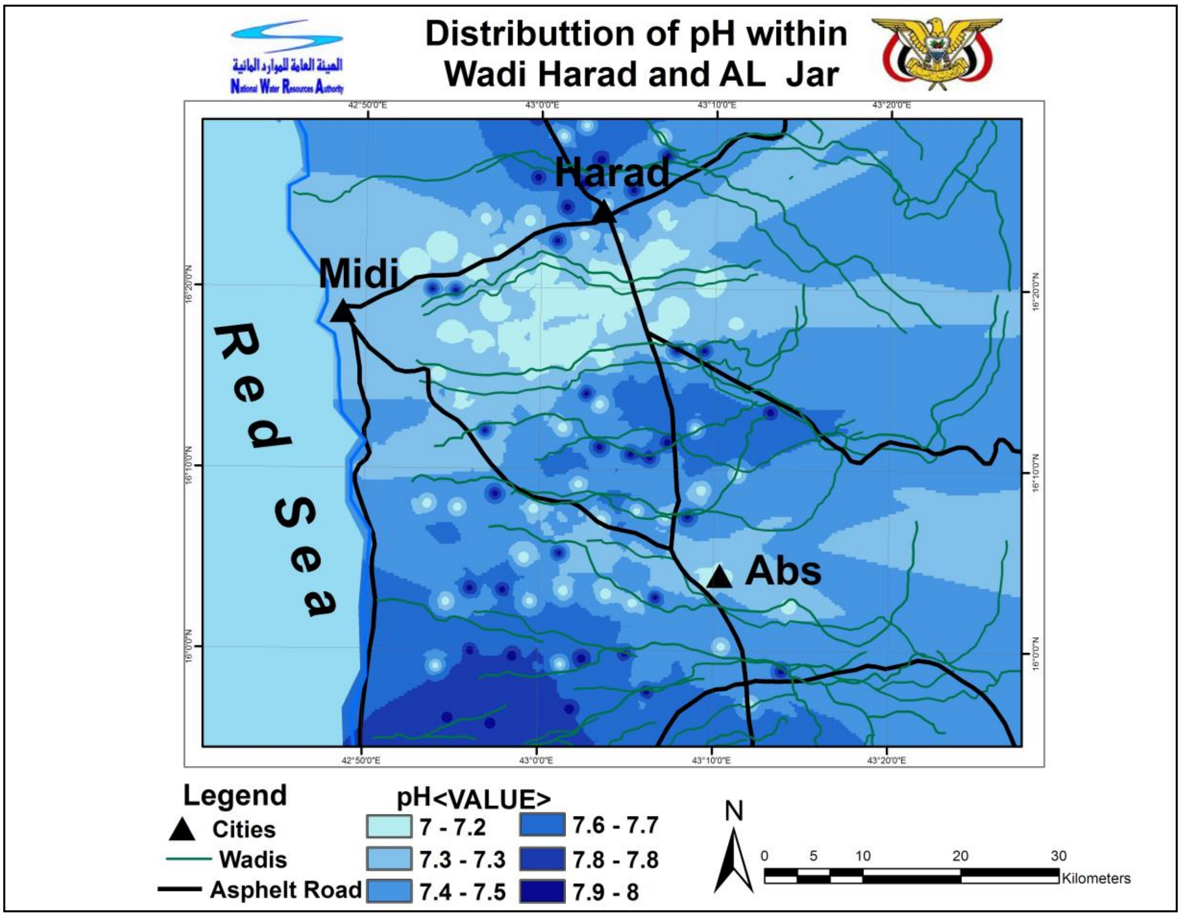


Figure 6: pH Distribution Within Wadi Harad and Al Jar

## Groundwater Temperature (oC):

The temperature increases approximately 1C for each 30m of depth according to the geothermal gradient of the earth crust, so the groundwater temperature may refer to depth of water. Measurement of temperature is required for control of other measurements, as all other parameters are sensitive to temperature. InWadi Harad and Al Jar all water samples, temperature varied between 27.9 oC -39.6 oC with average 34. 7 oC.

Figure 7 clearly illustrates the distribution the temperature in the water samples. The high concentration trends are increase west and south in area Al Jar.

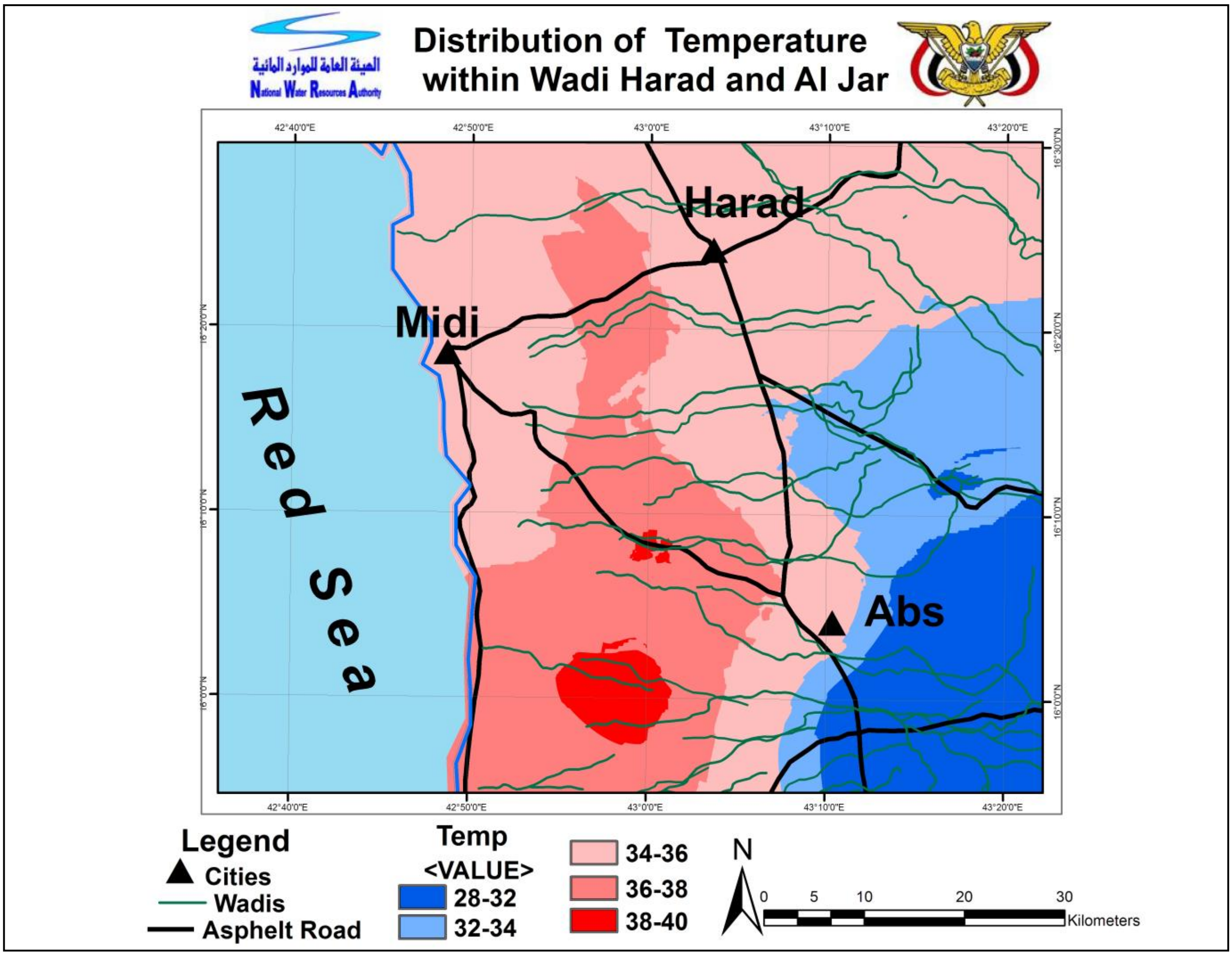


Figure 7: Temperature Distribution within Wadi Harad and Al Jar

## *2-3-3 Analysis & Data Processing*

### 2-3-3-1 Sample analysis

During the present study, the following chemical parameters in groundwater were analyzed at NWRA – Branch laboratory in Sana'a . The methods used are shown in the table 2.

Table 2: The chemical parameters in groundwater which analyzed

| Parameter | Method |
|---|---|
| Total Alkalinity | Titration with acid |
| Bicarbonate | |
| Carbonate | |
| Total Hardness, Calcium | EDTA Titrimetric method |
| Magnesium | Calculated from Calcium and Hardness results |
| Sodium | Flame photometry (JENWAY) |
| Potassium | |
| Chloride | Titration with $AgNO_3$ or $Hg(NO_3)_2$ |
| Sulphat | SulfaVer 4 with Barium |
| Nitrate | HACH Instrument |
| Florid | HACH Instrument |
| Iron | Atomic Adsorption |

The results of analysis for, Wadi Harad and Al Jar Samples are expressed in Appendix(2).

### 2-3-3-2 Quality of the analyses

Quality of the analyses was checked by three methods:

***Method** 1*- The ion balance, based on calculations of meq/l for cations and anions. The results are considered satisfactory if the calculated ionic balance error was less than 5%. Only 1 Sample exceed this ratio (5.1%).

***Method 2-*** Comparing total cations and anions (by meq/l) with the electrical conductivity. The EC is related to the ions which are present in solution. An EC of 100 µS/cm is equivalent to a concentration of about 1 meq/l of dissolved ions. The percentage deviation of the calculated EC from the measured EC was calculated, and the deviation found to range from 0 to 10%. All samples from study area were less than 10%.

***Method 3-*** Check TDS: The ratio between Measured TDS/ calculated TDS should be higher than1.0 and lower than 1.2 (1< Ratio TDS <1.2), because a significant contributor may not be included in the calculation. All samples from study area were between (1-1.2).

# 3- Evaluation of the Hydrogeochemical Processes

## 3-1 Methodology

The water samples were analyzed according to the Standard Methods for the Examination of Water for the ions (Cl-, HCO3-, SO4-2,NO3-, Ca+2,Mg+2,Na+, K+, F- and Fe+2).

Graphical and statistical methodologies were used to classify the water samples into homogeneous groups. Most of the graphical methods were designed to simultaneously represent the total dissolved concentration and the relative proportions of certain major ionic species (Hem, 1989). All the graphical methods used a limited number of parameters, unlike the statistical methods that can utilize all the available parameters. These graphical methodologies included the diagrams of Piper, Durov diagrams.

AquaChem version 3.6.2 for windows were used for graphical analyses. Statistical calculations were conducted by using SPSS 9.2 program for windows. Correlation analysis was conducted to study the relationships between parameters. The cluster analysis was used to test water – chemistry data and determine if the samples can be grouped into distinct populations (hydrochemical groups) that may be significant in the geological context, as well as from a statistical point of view (Guller etal., 2002). The hierarchical cluster analysis (HCA) was used to classify the samples into clusters (hydrogeochemical groups) based on their similarity.

Evaluation of the groundwater for drinking uses was carried out based on a comparison of the physical and chemical parameters in the water of wells with the drinking water guidelines of World Health Organization WHO (1996) and Yemen standards. Salinity hazard and Sodium Adsorption Ratio (SAR) will be used to evaluate the suitability of groundwater for irrigation purposes.

## 3-2 Result and Discussion

### *3-2-1- Groundwater Chemistry*

***1- Major Cations***

Calcium ( $Ca^{+}2$ )

Calcium is one of the most common ions in groundwater. One of the main reasons for the abundance of calcium in water is the weathering and decomposition of some rocks such as calcite ($CaCO_3$), Limestone, Dolomite $CaMg(CO_3)_2$, Gypsum $Ca\ SO_4$-$2H_2O$, Anhydrite $CaSO_4$, fluorite and apatite. Calcium reacts with water at room temperature, according to the following reaction mechanism:

$$Ca\ (s) + 2H_2O\ (g) \longrightarrow a\ (OH)_2\ (aq) + H_2\ (g)$$

This reaction forms calcium hydroxide that dissolves in water as a soda, and hydrogen gas. Calcium salts in water $Ca\ (HCO_3)_2$, $CaCO_3$, and $CaSO_4$. Calcium are very important for water used in agricultural purposes, where it reduces the sodium absorption ratio of water and tries to diminish the effect of sodium through base cation exchange. In the Wadi Harad and Al Jar Calcium content ranges 28mg/l – 599 mg/l with average 138 mg/l.

Figure 8 clearly illustrates the distribution the calcium concentration in the area,
It shows an increase in the concentration the western parts of the study area in Midi

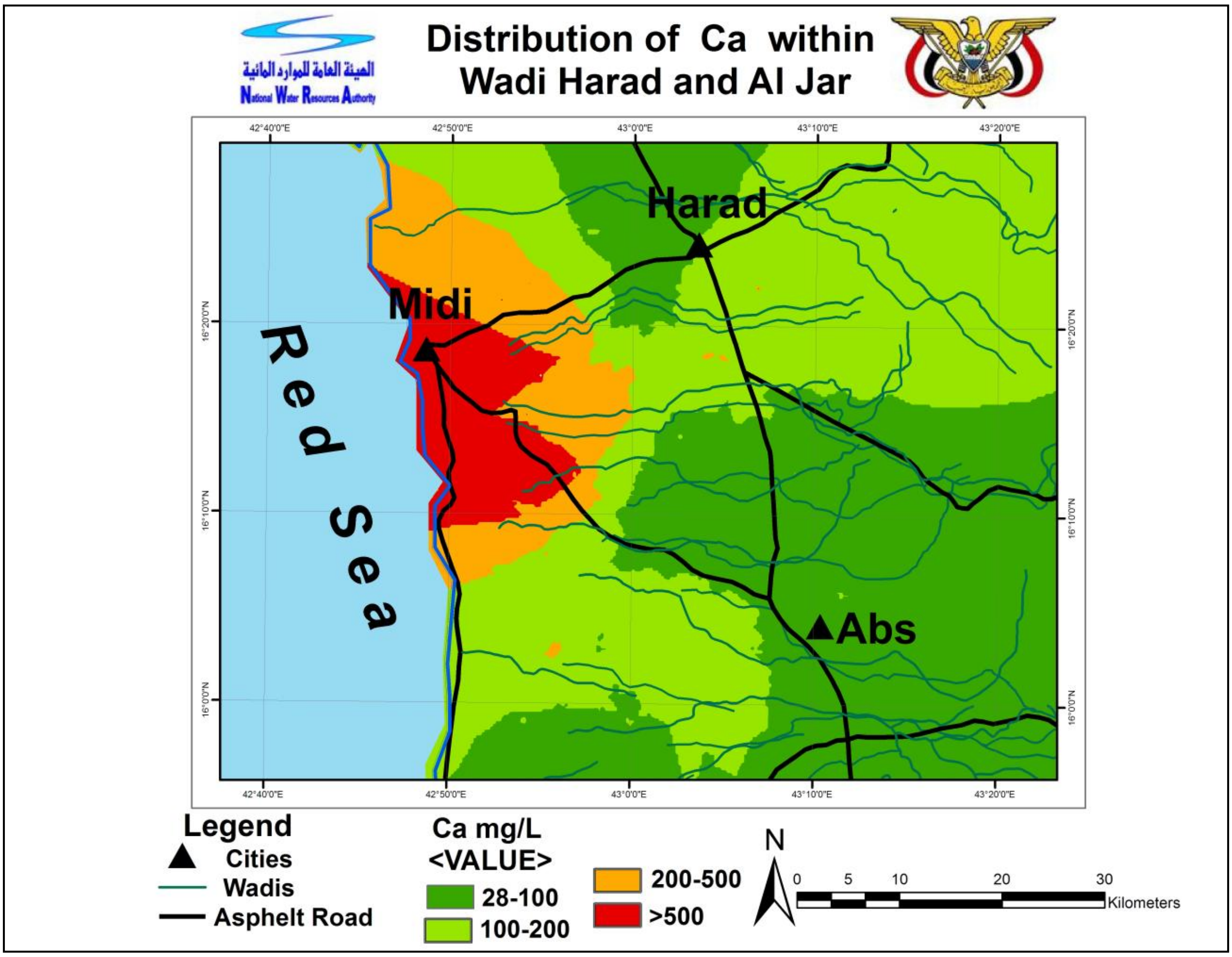


Figure 8: Calcium Concentration map in Wadi Harad and Al Jar

### Magnesium ( $Mg^{+2}$ )

The main source of magnesium in the water is weathered igneous rocks which contain olivine, pyroxene, amphibole and mica minerals. Also it is found in metamorphic and sedimentary rocks and especially in amphibolite schist, dolomite and magnesite. Magnesium is washed from rocks and subsequently ends up in water. The magnesium salts found in groundwater are $MgCO_3$, $Mg(HCO_3)_2$, $MgSO_4$ . The presence of magnesium in the groundwater is useful for agricultural purposes as it flocculates the soil colloids and they increase the permeability of the soil.

In the Wadi Harad and Al Jar Magnesium content ranges 15mg/l – 427 mg/l with average 138 mg/l.

Figure9 clearly illustrates the distribution the magnesium concentration in the area. It shows an increase in the concentration toward the western parts of the study area in Wadi Harad and Al Jar.

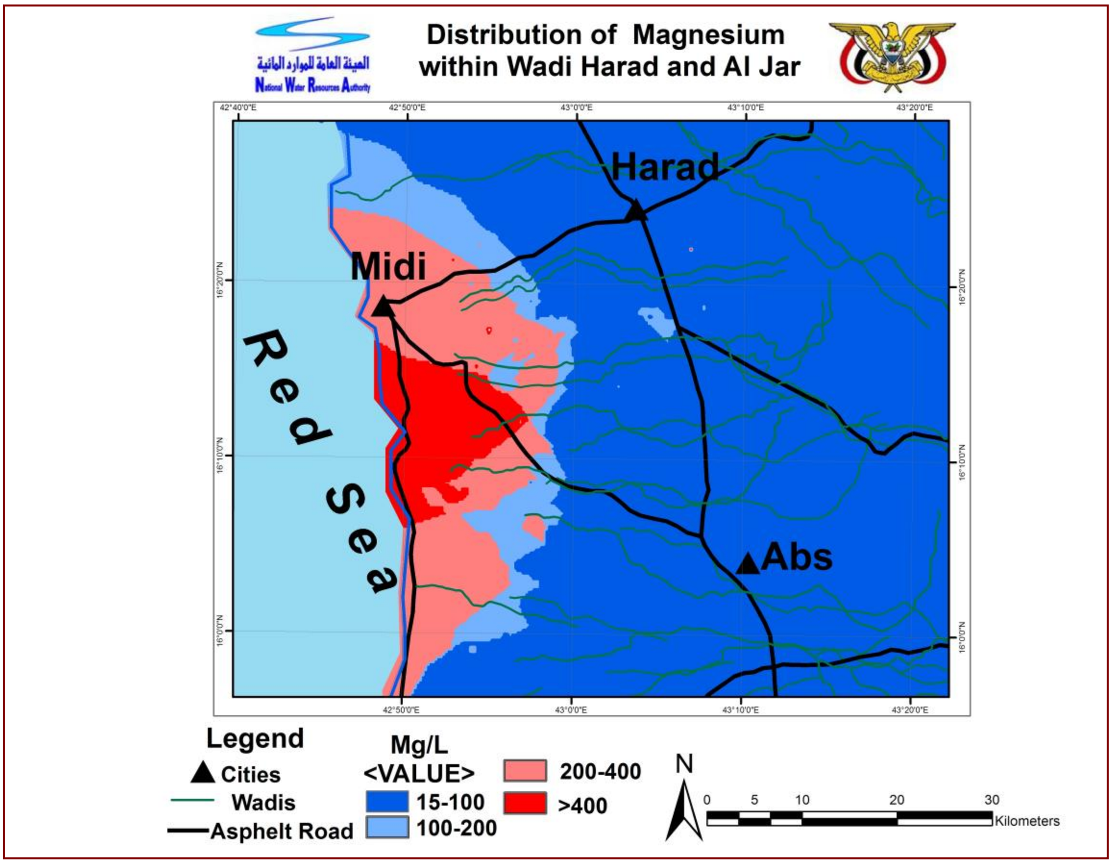


Figure9: Magnesium Concentration map in Wadi Harad and Al Jar

### Sodium (Na+)

The main source of sodium in groundwater is weathered and dissolved igneous and metamorphic rocks which contain feldspathic minerals. Alluvial deposits yield water with relatively high sodium content. The sodium content in the groundwater may increase as a result of cation exchange between the sodium from the aquifer material and calcium found in water. The sodium salts found in water are NaCl and Na2 SO4 .Sodium is the sixth most abundant element in the Earth's crust, which contains 2.83% of sodium in all its forms. Sodium is after chloride, the second most abundant element dissolved in seawater. The most important sodium salts found in nature are sodium chloride (halite or rock salt). In the Wadi Harad and Al Jar Sodium content ranges 34.1mg/l –1395.9 mg/l with average 256 mg/l.

Figure 10 clearly illustrates increasing sodium element on the west of Wadi Harad and Al Jar and extended on the coast line to south-west near Midi.

The increase the salinity in these areas may be caused by connate water of marine origin, recharge from coastal precipitation, or return flow from irrigation waters or from sea water intrusion to fresh water.

The chemical water type in these area is NaCl, which refers to the marine original of this water .

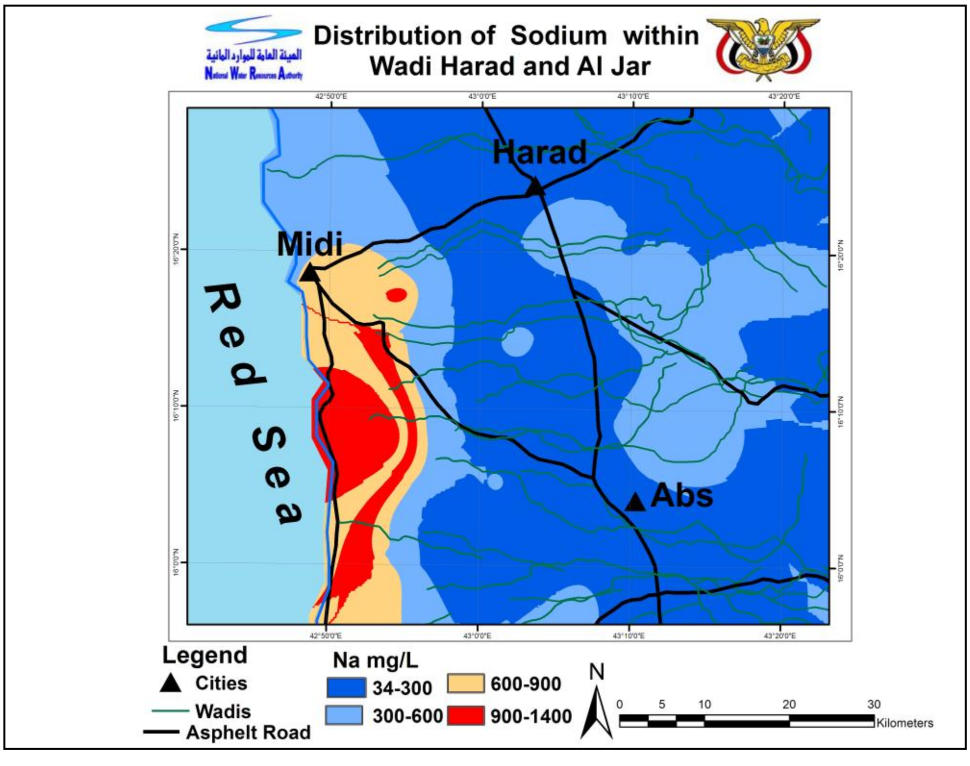


Figure 10: Sodium Concentration in Wadi Harad and Al Jar

### Potassium (k+)

Potassium is slightly less common than sodium in igneous rocks, but potassium is more abundant in all the sedimentary rock. The main source of potassium in groundwater is potassium feldspars and feldspathoid in igneous rocks, clay minerals in sedimentary rocks and in evaporate rocks. Potassium salts in water are KCl and in evaporate rocks. Potassium salts in water are KCl and K2SO4. In the Wadi Harad and Al Jar potassium content ranges between 0.5 mg/l- 10.4 mg/l with average 3.52 mg/l

Figure 2 clearly illustrates the Potassium values in Wadi Harad and Al Jar, which is normal in all area

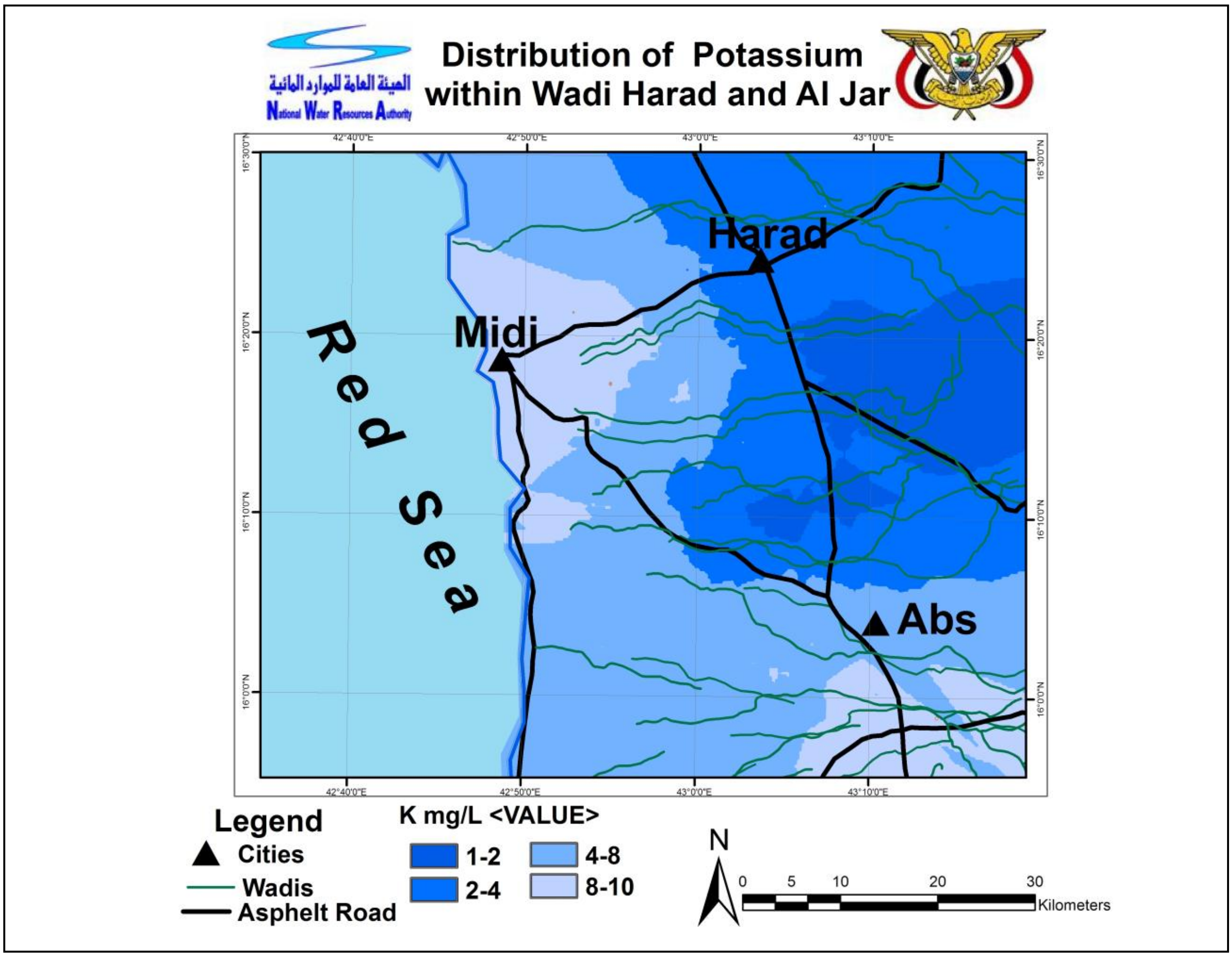


Figure 11: Potassium Concentration in Wadi Harad and Al Jar

***2- Major anions***

Carbonate (CO3-) and Bicarbonate (HCO3-)

The main source of carbonate and bicarbonate is carbon- dioxide (CO2) from the atmosphere. Carbon dioxide released within the soil by organic decay and from plant respiration. In the Wadi Harad and Al Jar carbonate was not found in any samples.

The concentration of bicarbonate in the Wadi Harad and Al Jar ranges between 70 mg/l – 485 mg/l with average 225 mg/l .

Figure 12 shows the distribution of the bicarbonate concentration in the study area, many areas contain a high concentration of bicarbonate, but most of the areas with Bicarbonate concentration are in the east of Abs. The concentration map of bicarbonate shows the highest concentration in the east parts , south east of the study area.

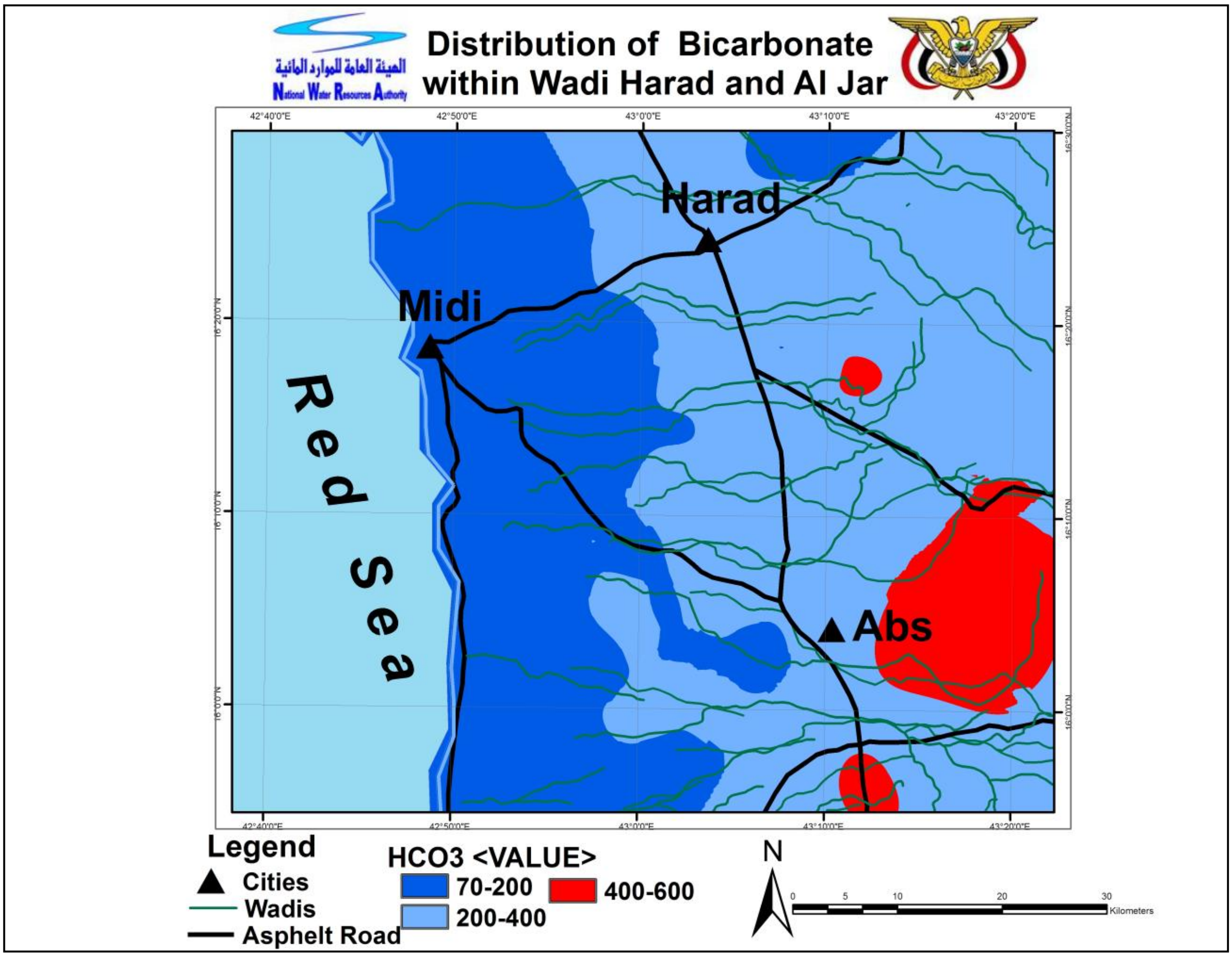


Figure 12 Concentration of Bicarbonate in Wadi Wadi Harad and Al Jar

Sulphate (SO4 -2)

Sulphate is not a major constituent of the earth outer crust, but is widely distributed in reduced form both in igneous and sedimentary rocks of metallic sulfides. These sulfides (such as pyrite) are oxidized to yield Sulphate ions which are carried off in the water (Hem 1970). In the Wadi Harad and Al Jar ranges between 23 mg/l – 866 mg/l with average 239 mg/l

Figure 13 shows the distribution of the sulfates concentration in the study area As can be seen high proportion of sulfates in the western in Midi regions and gradually less as we head east.

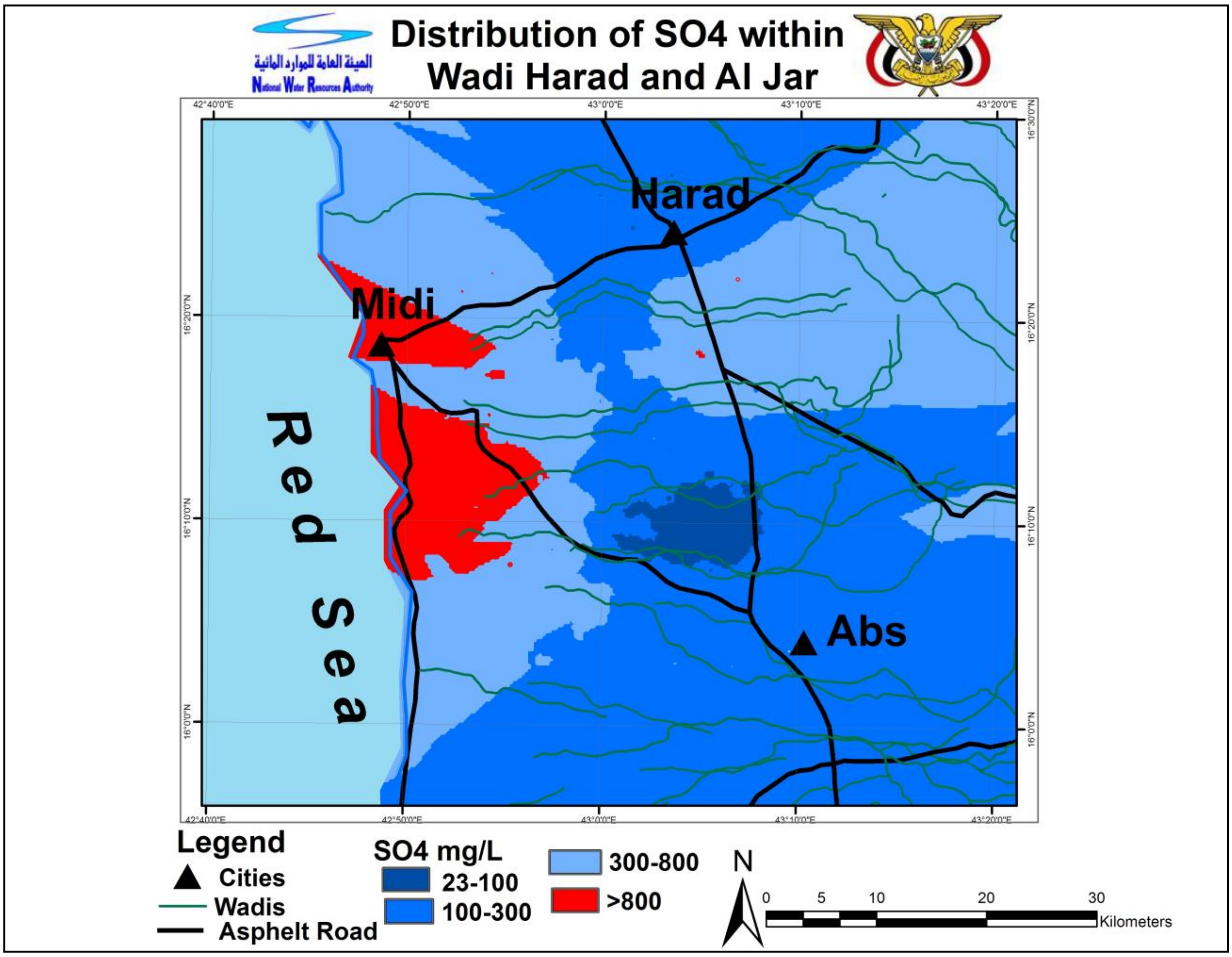

Figure 13: Concentration of Sulfate in Wadi Harad and Al Jar

Chloride (Cl-)

Chloride is one of the most commonly occurring anions in the environment. In natural water, the main source of chloride is from feldspathoid sodalite in igneous rocks and halite in evaporate which is washed from these rocks and subsequently ends up in water.

Chloride content in Wadi Harad and Al Jar ranges between 27mg/l – 3533 mg/l with average 487 mg/l .

Figure 14 shows an increase in chloride contamination in the coastal area with the same increasing in sodium element, So, this figure implies that the increase in concentration of the chloride may be the result of salt water intrusion into fresh water (chloride is the main anion in the sea water).

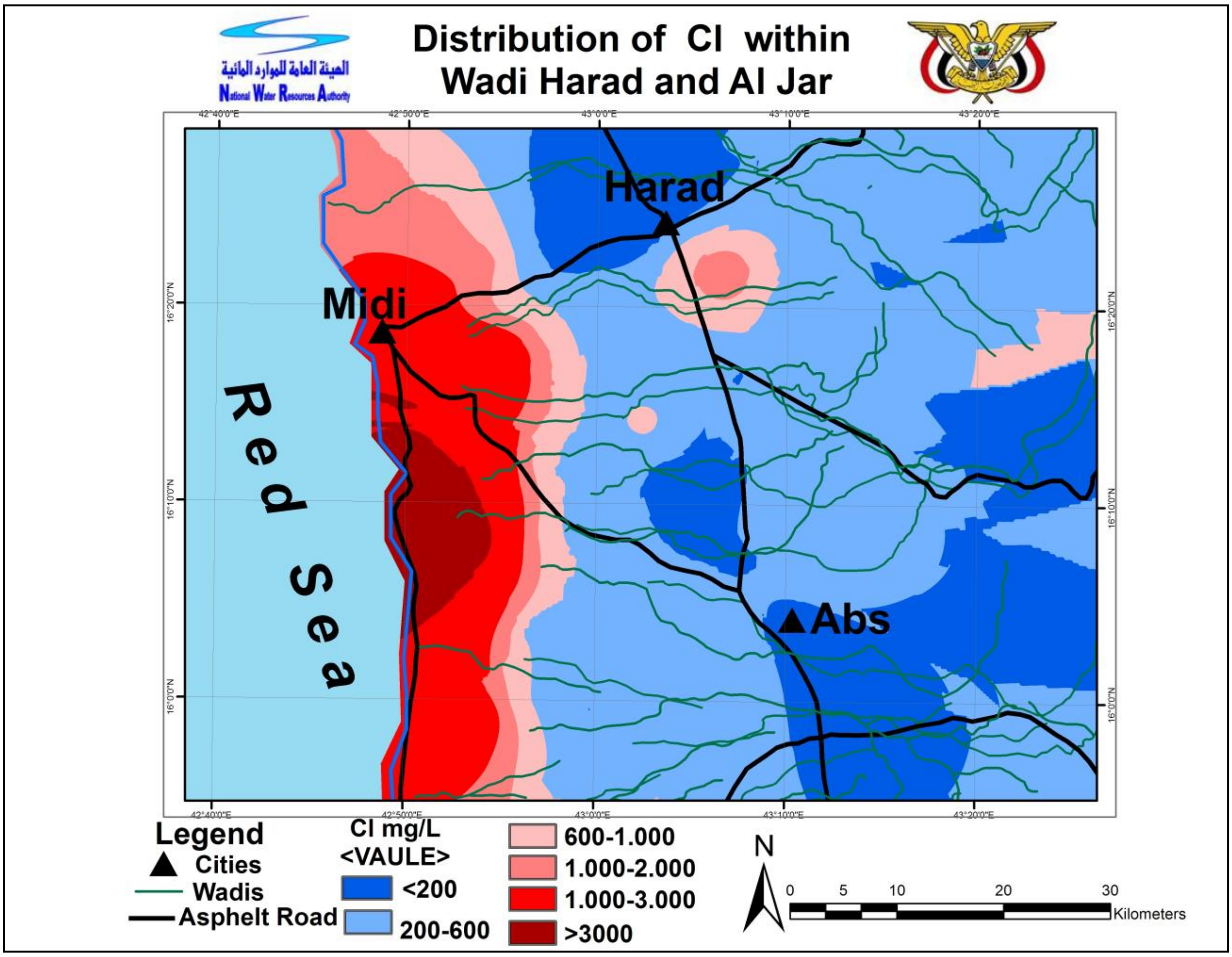


Figure 14: Concentration of Chloride in Wadi Harad and Al Jar

Nitrate NO3

In Wadi Harad and Al Jar ranges from3.52mg/l-640mg/l with an average of 75.5 mg/l thirty four samples have shown values higher than 50 mg/l (Yemen and WHO Guideline Value) is probably due to the use of nitrogenous fertilizers and to the crop watering practices based on irrigation by flooding. The nitrogen contained in the fertilizers is only partly absorbed by the crops. The remaining portion percolates as a solution into the groundwater in the form of ammonium that oxidizes fast into nitrite and finally into nitrate (stable form in the presence of oxygen). This remarkable spreading of nitrates in the groundwater of this area represents a major problem for drinking water supply. It brings about methemoglobinemia in babies. Moreover, when compounded with some food preservatives it is suspected to unleash carcinogenic activity. Figure 15 shows nitrate distribution in the study area . increase in nitrate in the coastal area

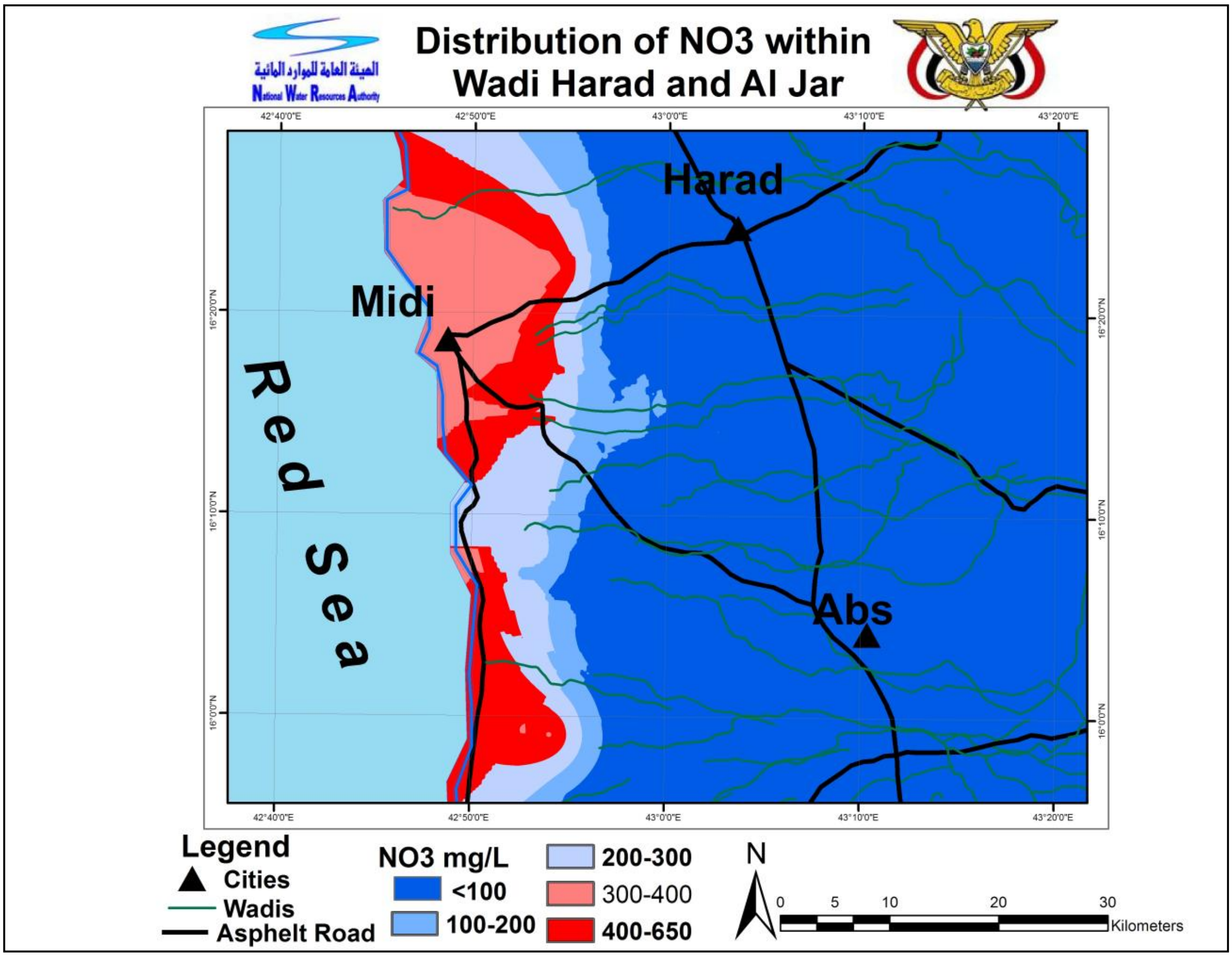


Figure 15: Concentration of Nitrate in Wadi Harad and Al Jar

Fluoride (F)

The presence of Fluoride in drinkable water is of the highest importance, as it contributes to protect tooth enamel. Values found range from 0.1 – 1.55 mg/l in Wadi Haradh and Jar.

There are 1 sample which exceed the Yemeni standard for drinking water (Yemen standard ranges between 0.5-1.5 mg/l) in Harad and Al Jar .

High values of fluoride in the study area can be attributed to the usage of phosphatic fertilizers and the fluoride – containing minerals in the study area through which the groundwater is circulating.

Figure 16 clearly illustrates the fluoride values in Wadi Harad and Al Jar, which is normal in all area.

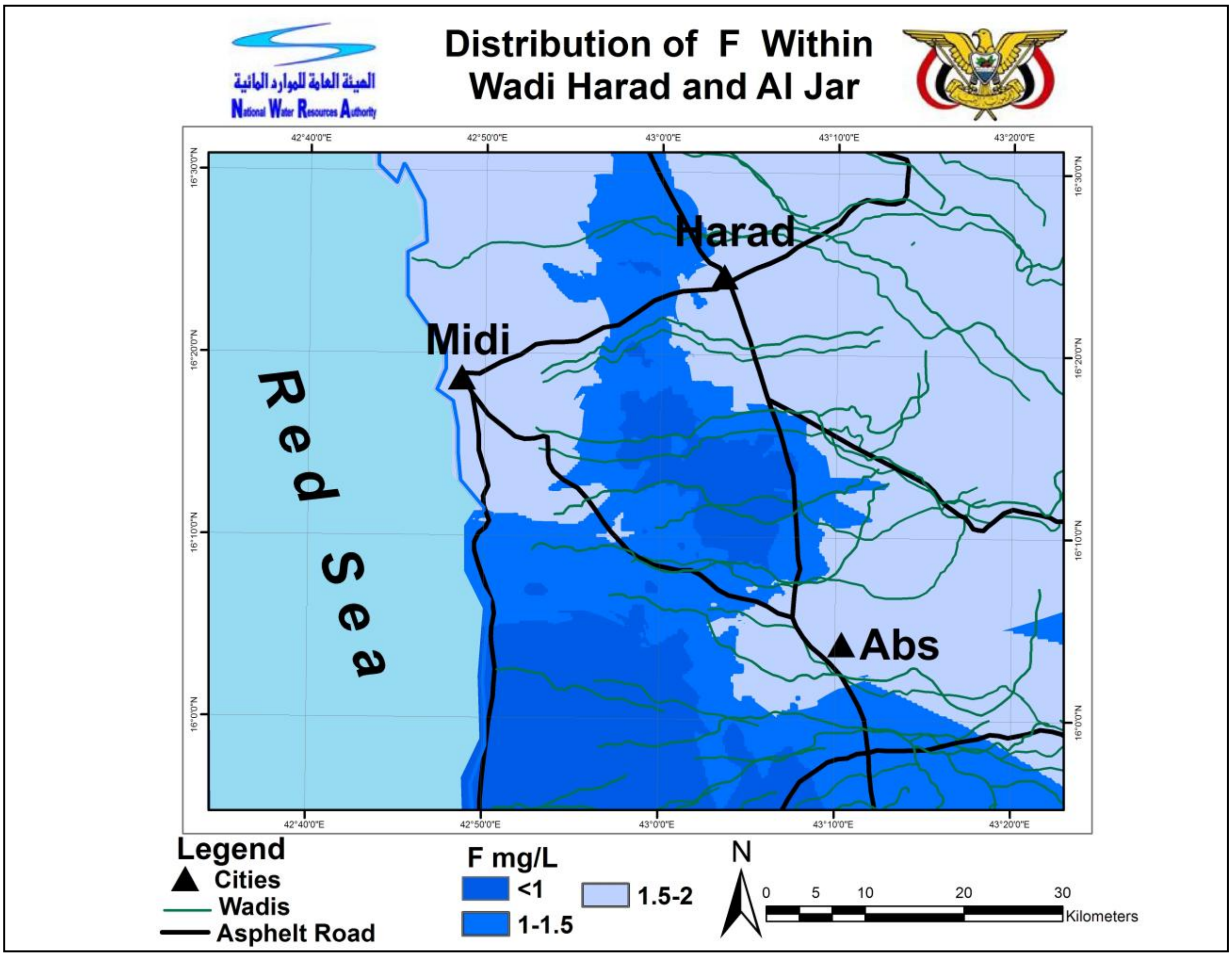


Figure 13: Concentration map of Fluoride in Wadi Harad and Al Jar

The average, minimum and maximum values for each water quality parameter analyzed for the study area is presented in Table 3 with the percentage of water samples which exceed the Yemen drinking water standard .

Table 3: Summary of the physical and chemical characteristics of the studied samples (91 wells) in Wadi Harad andAl Jar (Concentrations in mg/l, EC in µS/cm)

| Parameter | Average | Max. | Min. | Percentage of samples [a] | Parameter | Average | Max. | Min. | Percentage of samples [a] |
|---|---|---|---|---|---|---|---|---|---|
| pH | 7.3 | 8.3 | 6.4 | | Mg | 71 | 427 | 15 | 12 |
| T | 34.7 | 39.6 | 27 | | Cl | 487 | 3533 | 27 | 28 |
| EC | 2018 | 9990 | 438 | 32 | HCO3 | 225 | 485 | 70 | 0.7 |
| TDS | 1529 | 7553 | 1339 | 32 | SO4 | 239 | 866 | 23 | 20 |
| TH | 638 | 3172 | 171 | 42 | NO3 | 75.5 | 640 | 3.52 | 38 |
| Na | 256 | 1395 | 34 | 26 | Fe | 0.0609 | 0.83 | 0 | - |
| K | 3.52 | 10.4 | 0.5 | - | F | 0.56 | 1.55 | 0.1 | 21 |
| Ca | 138 | 599 | 104 | 13 | | | | | |

[a] Percentage of samples beyond the permissible limits as prescribed by Yemen Standard (2001)

## Total Hardness

Total Hardness is conventionally expressed as total concentration of Ca and Mg (milligrams per liter) equivalent to CaCo3 and associated with water type. It commonly makes soap difficult to rinse and causes scaling in boilers and kettles is commonly used. Water is designated as being soft or heavy if its hardness is less than 60 mg/l or greater than 180 mg/l, respectively (Hem, 1985). However this classification is not practical for use. NWRA has set 500 mg/l as the maximum permissible limit for total hardness

In Yemen to determine the suitability of groundwater for domestic use.

In the study area,in wadi Mawr values range from 70 - 2560 mg/l with average 854 mg/l. There are 81 samples exceed the Yemeni standard for drinking water While (Yemen standard ranges between 100-500 mg/l). While 25 samples under the (Yemen standard ranges between 100-500 mg/l). While In the study area,in wadi Haradh and Jar values range from 171 -3172 mg/l with average 638 mg/l

There are 44 samples exceed the Yemeni standard for drinking water While (Yemen standard ranges between 100-500 mg/l). While47 samples under the (Yemen standard ranges between 100-500 mg/l).

## 4- Chemical water type in Wadi Mawr and Haradh

Classification of water samples provide a basis for grouping samples with similar characteristics. Most of the classification systems developed to date have considered only the major inorganic constituents and have ignored the organic and the minor and trace inorganic constituents. In this section graphical and statistical methodologies were used to classify the water samples into homogeneous groups.

There are many methods to classify water and determine the chemical water type, but The Piper diagram is the best because of its many advantages such as :

- Many water analyses can be plotted on the same diagram
- Can be used to classify water
- Can be used to identify the mixing of types of water

According to The Piper diagram that was used to identify groundwater chemical water types for 106 samples collected from Wadi Mawr, the analysis of the main ion chemistry and by using conversion constants to transform anion and cation values - expressed in mg/l - into meq/l, it is possible to interpret the chemical water type of a given sample of water.

To explain the chemical water types for all area , the Wadi was divided into two parts; upstream including the area mawr than UTM – E 310000m; down stream less than 310,000m.The Piper diagram has allowed for the identification of two chemical water type, which relate directly to the history and development of the groundwater. Also, the chemical types for the two parts of the wadi are presented in the figures (18 A, B) and discussed below.

## 4-1 Types of the chemical water

### *4-1-1Chemical Classification of Water Wadi Harad and Al Jar*

Requires classification of water and Wadi Harad and Al Jar chemically to know how many kinds of chemical compositions of the samples studied and this purpose was used scheme piper digram form (17) where it was him dropping the results of chemical analysis of the samples studied after converting the concentrations of positive and negative ions of the chemical elements of the mg / L to Milli eq / L Depending on the weight equivalent of each element. this plan pointed to the existence of three chemical compositions. two types are considered and the third and fourth are considered at least a percentage of the basin.

**1- (Ca+Mg) (So4+Cl)**

This type of chemical composition are considered in the first place from where he was in the pelvis was found in 50 samples (54%) were seen spread in abundance volcanic rocks in the Wadi deposits, which are found concentrated in areas near the stream Wadi, where in such areas the proportion of feeding rainwater These areas amount to the largest.

**2- (Ca +Mg )(HCo3)**

But this kind in the region found in 9 samples (10%) This is found in volcanic rocks, and according to the classification Diorov 1948, this water is fresh water and called the initial water (primary water) is also known that the source staple of Ion bicarbonate in the groundwater is the melting of CO2 in the atmosphere and comes down with rain, which in turn run into the ground and this usually indicates the occurrence of feeding the underground water is found in south-eastern areas of the mouth of the Wadi where there are clear and volcanic rocks in the mountains nearby.

**3- (Na+K) (So4+Cl )**

This type is Conceive in terms of his presence in the basin, where 30 sample found (33%) and you see the volcanic rocks In the western areas of the Wadi on part northerly and southerly away from the stream Wadi where Increase concentration of salts as a result of attrition iniquitous groundwater and increased temperature and evaporation rate Increase and distance from the stream wadi and recharge areas.

**4- (Na+K)(HCo3)**

This type is less species in the samples distributed on a basin level was found in 2 samples(3%) and the samples are found in deep wells drilled in the Volcanic and existence of this magnitude indicates the presence of a weak ionic exchange.

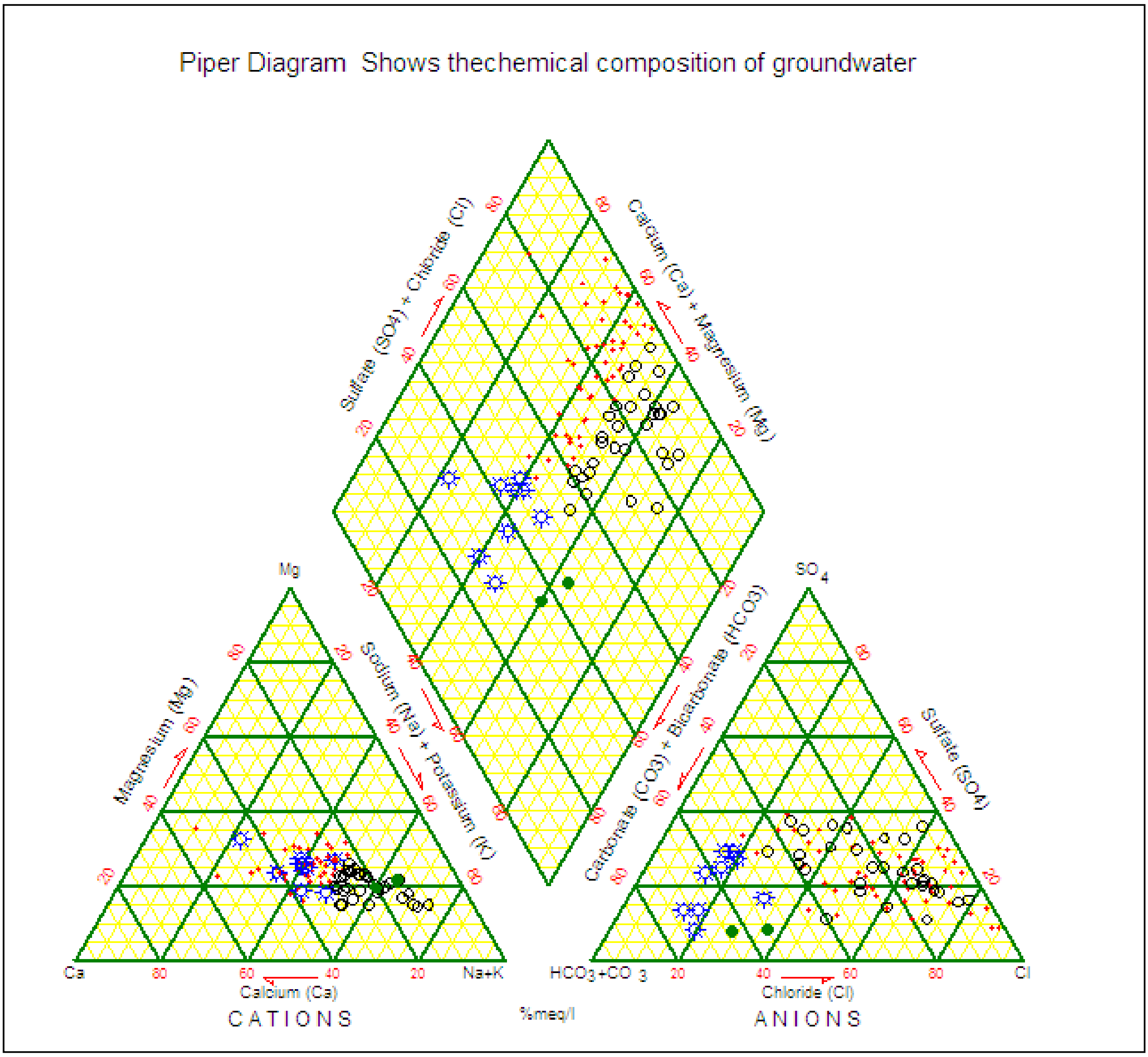


Figure 17: The Piper Digram of Wadi Harad and Al Jar

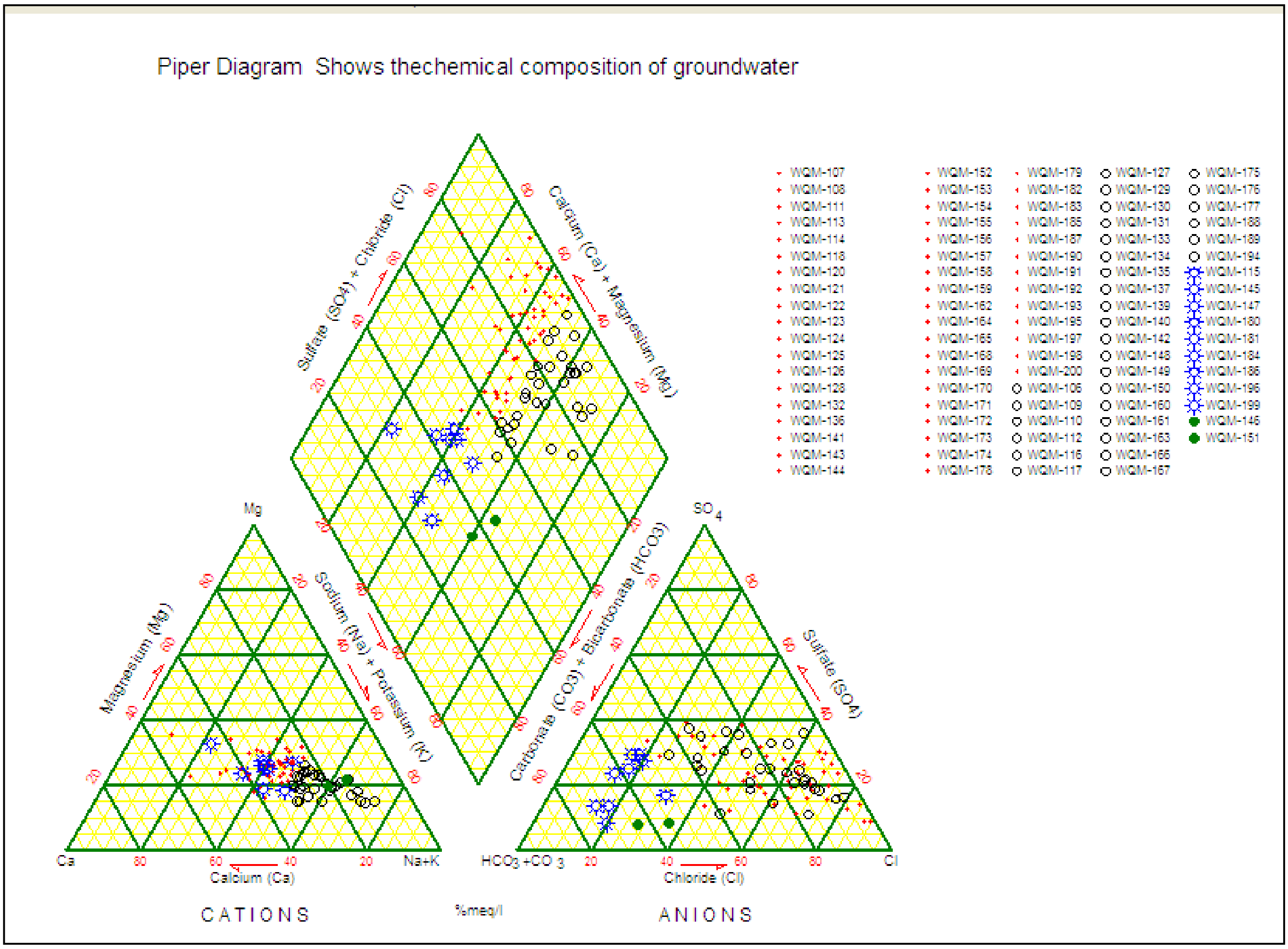


Figure 18: The Piper Digram of Wadi Harad and Al Jar

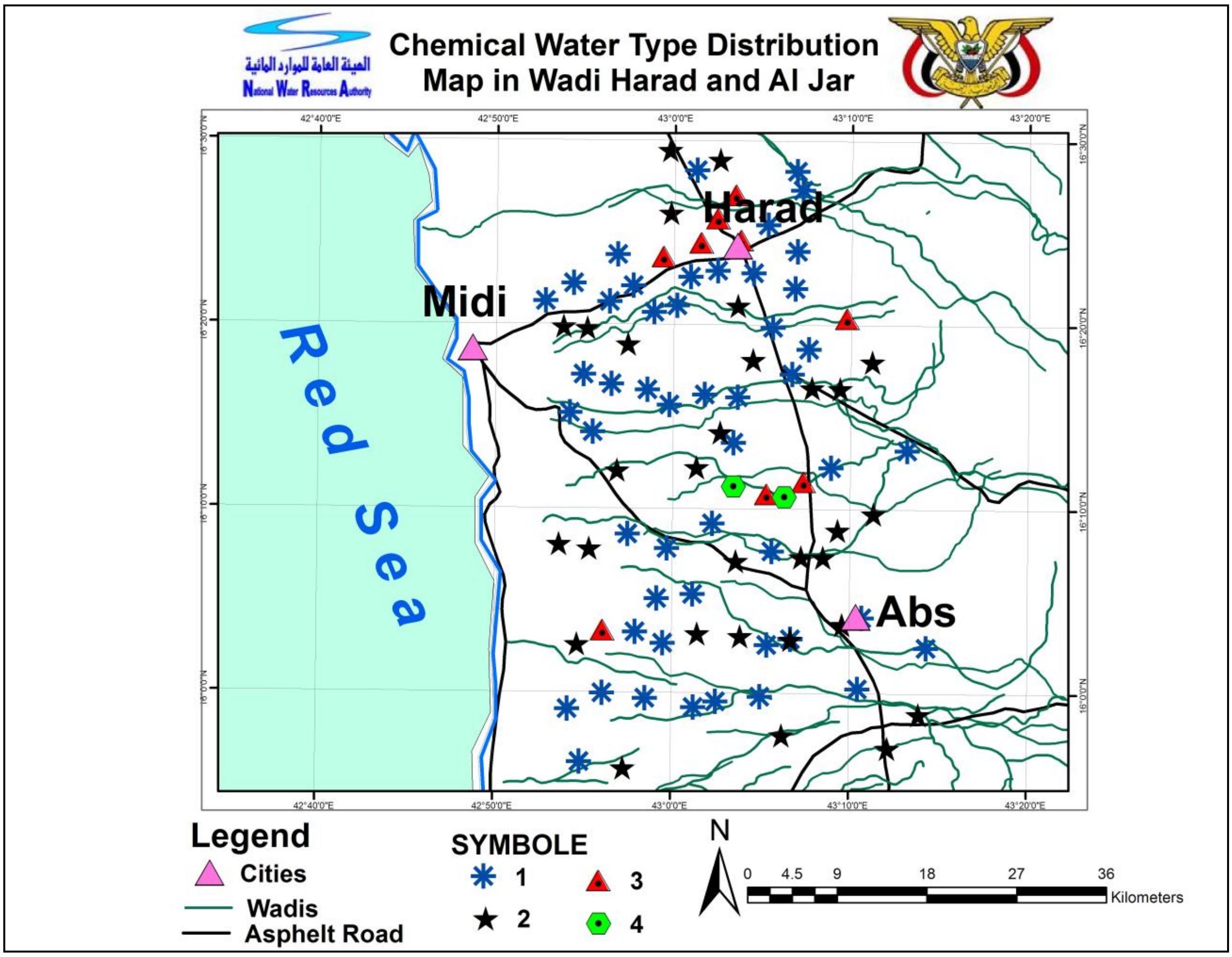


Figure 19: Chemical Water Type Distribution Map in Wadi Harad and Al Jar

## 4-2 Salt water Intrusion

The salt water intrusion happen when there is a reduction in the fresh water head and flow at the sea water interface. This commonly occurs when there is over pumping or insufficient groundwater recharge of an aquifer in the coastal zone.

This phenomena happened due to the differences in density of sea water and fresh water . Fresh water has a density of 1.0g/cm3 whilst salt water is slightly denser: 1.025g/cm3. Because of this fresh water floats on top of the sea water. The underground boundary that separates the fresh water layer from the salt water is not a sharp boundary line. In reality, this boundary is a transition zone of brackish water (fresh/salt mixture) as shown in the figure 26.

The mathematical formula ( Ghyben-Herzberg Relation) for the fresh to salt water relationship is:

$$H = \frac{\rho_f}{\rho_s - \rho_f} \times h = 40 \times h$$

Where

H is the depth of fresh water below sea level

h is the depth of fresh water above sea level

$\rho_s$ is the density of salt water

$\rho_f$ is the density of fresh water

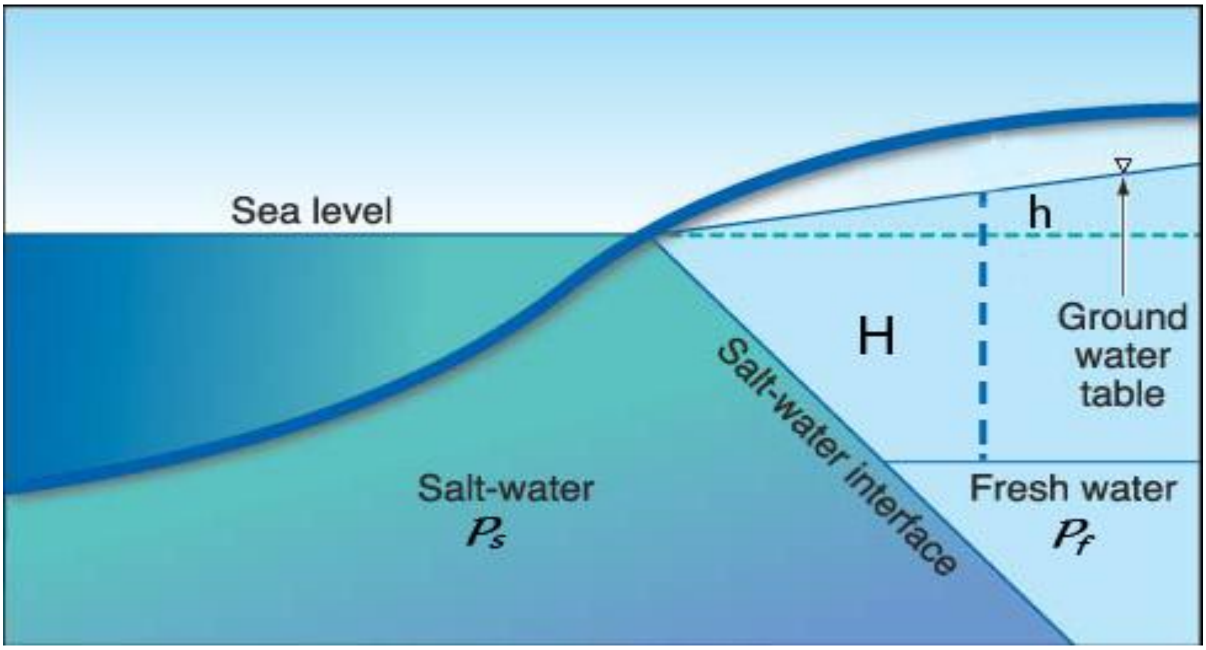


Figure 20: Salt water Intrusion phenomena

According to this relation, if the water table in an unconfined coastal aquifer is lowered by 1 m, the salt-water interface will rise 40 m.
In Wadi Harad and Al Jar , especially  in Al Jar ,Midi and Harad is greatly influenced by many of borehole and dug wells whish is over pumping to abstraction water for human and agriculture uses . Yet the seasonal fluctuations in rainfall also greatly influences this zone. These  wells that penetrate deeply within this transition zone results in sea water intrusion.

# 5- Groundwater Use

## 5-1 Introduction

Whether a groundwater of a given quality is suitable for a particular purpose depend on the standards of acceptable quality for that use. Quality limits of water supplies for drinking water, Industrial purposes, and irrigation apply to groundwater on account of its extensive development for these purposes.

In total, 197 water samples were analyzed throughout Wadis Mawr and Haradh part of this study. This section discusses the suitability of groundwater for various uses, and the evidence of groundwater pollution in the project area.

The suitability of water quality for different uses is assessed using Yemeni and/or international standards.

## 5-2 Drinking ( Domestic) Water in Wadi Haradand AlJar

The water quality parameters used were the Yemeni standards for drinking water set by the National Water Resources Authority (NWRA). These standards generally apply to two limits, the optimal limit (OL) and the maximum permissible limit (MPL).

Despite only 9 of the wells sampled being from water domestic projects, all analysed samples were assessed for suitability as drinking (domestic) water. This is mainly because, despite the primary use of wells as being for irrigation, farmers not connected to public mains commonly use the water for domestic purposes.

Summary of the quality classification of suitability for domestic/drinking use for all analyzed samples are given in Table (4).

It should noted that very few samples were found to be over the Maximum Permissible Limit (MPL), and more than 94 % of the samples had levels between Optimal Limits and Maximum Permissible Limit.

With respect to Nitrate element, only 11 % of samples (1 sample) were found over Maximum Permissible Limit (MPL). These samples were concentrated in the west / north of the study area, and for Chloride, about 11% of samples (1 samples) were found over Maximum Permissible Limit (MPL).

These samples were concentrated in the west of the study area on coast and may be affected by salt water intrusion (chloride map ).

Also for fluoride, about 0 % (0 sample) were found over Maximum Permissible Limit (MPL)

Table 4: Suitability of water samples for drinking water in Wadi Harad

| Element | Optimal Limits (mg/l) | Samples within (OL) | Maximum Permissible Limit(mg/l) | Samples within (MPL) | Samples over the (MPL) |
|---|---|---|---|---|---|
| **TDS** | 650 | 1 | 1500 | 6 | 2 |
| **Calcium** | 75 | 1 | 200 | 8 | 0 |
| **Magnesium** | 30 | 1 | 150 | 8 | 0 |
| **Sodium** | 200 | 7 | 400 | 2 | 0 |
| **Potassium** | 8 | 9 | 12 | 0 | 0 |
| **Bicarbonate** | 150 | 0 | 500 | 9 | 0 |
| **Chloride** | 200 | 1 | 600 | 7 | 1 |
| **Sulfate** | 200 | 6 | 400 | 3 | 0 |
| **Nitrate** | 10 | 0 | 50 | 8 | 1 |
| **Iron** | 0.3 | 9 | 1 | 0 | 0 |
| **Flouride** | 0.5 | 3 | 1.5 | 6 | 0 |
| **Total Hardness** | 100 | 0 | 500 | 7 | 2 |

## 5-3 Water supply in wadi Harad and Al Jar

It should noted that 74% of the supply wells ( 25 wells) are classified as unsuitable for drinking water on account of one element or more exceeded the Yemeni standard. More than 12 % (4 samples) of samples were had levels higher than the MPL with respect to Nitrate and more than 3% of samples (1 sample) had levels higher than the MPL with respect to fluoride.

Table 5: Suitability of water samples for supply water in Wadi Harad

| Element | Optimal Limits (mg/l) | Samples within (OL) | Maximum Permissible Limit(mg/l) | Samples within (MPL) | Samples over the (MPL) |
|---|---|---|---|---|---|
| **TDS** | 650 | 5 | 1500 | 14 | 6 |
| **Calcium** | 75 | 11 | 200 | 11 | 3 |
| **Magnesium** | 30 | 9 | 150 | 16 | 0 |
| **Sodium** | 200 | 18 | 400 | 5 | 2 |
| **Potassium** | 8 | 23 | 12 | 2 | 0 |
| **Bicarbonate** | 150 | 1 | 500 | 24 | 0 |
| **Chloride** | 200 | 13 | 600 | 9 | 3 |
| **Sulfate** | 200 | 15 | 400 | 9 | 1 |
| **Nitrate** | 10 | 4 | 50 | 17 | 4 |
| **Iron** | 0.3 | 8 | 1 | 17 | 0 |
| **Flouride** | 0.5 | 13 | 1.5 | 11 | 1 |
| **Total Hardness** | 100 | 0 | 500 | 15 | 10 |

Table 6: The water samples exceed the Yemeni standard of Drinking Water in Wadi Harad and Al Jar

| Well No | Site | Well type | Location | | N0. of exceed elements | Exceed Element Type |
|---|---|---|---|---|---|---|
| | | | UTM East | UTM North | | |
| **WQM 106** | Dyer Al Hasy | Bore | 297958 | 1775291 | 1 | F |
| **WQM 107** | Bani Labnyh | Bore | 295591 | 1774710 | 3 | TDS,TH,Ca |
| **WQM 108** | Village Al Sokef | Bore | 292916 | 1775651 | 5 | TDS,TH, EC,Ca,Cl |
| **WQM 112** | Al Galahef | Bore | 288150 | 1779846 | 3 | TDS,TH, EC |
| **WQM 121** | Abs | Bore | 288203 | 1768491 | 1 | NO3 |
| **WQM 129** | Village Lebadh | Bore | 297058 | 1765689 | 5 | TDS,TH, EC,Na,Cl |
| **WQM 135** | Al Tenah | Bore | 281648 | 1785905 | 1 | NO3 |
| **WQM 139** | Al Mhsam | Dug | 302732 | 1786203 | 6 | TDS,TH, NO3,EC,Cl,Na |
| **WQM 152** | Sadh Al | Bore | 292748 | 1799543 | 2 | TH,NO3 |
| **WQM 157** | Bani Al Zayn and Bani Fadel | Bore | 289427 | 1799835 | 1 | TH |
| **WQM 158** | Al Asar | Dug | 302080 | 1792437 | 3 | TDS, TH, Ca |
| **WQM 161** | Al Awga Village | Bore | 300210 | 1800497 | 1 | TH |
| **WQM 163** | Al Farsh | Dug | 306252 | 1803085 | 3 | TDS, TH, EC |
| **WQM 165** | Village Al Ten | Bore | 296296 | 1806523 | 6 | TDS, TH, EC,Cl,NO3,So4 |
| **WQM 169** | Village Al Karsh | Dug | 298774 | 1814142 | 1 | TH |
| **WQM 172** | Al Hegarh Village | Bore | 288047 | 1811665 | 2 | TH,NO3 |
| **WQM 182** | Al Project Village Kdra | Bore | 282309 | 1810786 | 1 | NO3 |

## 5-4 Evaluation of water quality for irrigation uses

The suitability of water for irrigation is determined by its mineral constituents and the type of the plant and soil to be irrigated. Many water constituents are considered as macro or micro nutrients for plants, so direct single evaluation of any constituent of these constituents will not be of great value unless a complete analysis of soil and plant specifications are conducted were adopted internationally based on the general criteria which represent combinations of the different water parameters (i.e. salinity (EC), SAR and SSP) parameters for the evaluation of water quality for irrigation purposes, and will be used in this work.

### *5-4-1 Salinity*

Excess salt increases the osmotic pressure of the soil water and produces conditions that keep the roots from absorbing water. This results in a physiological drought condition. Even though the soil appears to have plenty of moisture, the plants may wilt because the roots do not absorb enough water to replace water lost from transpiration. Based on the EC, irrigation water can be classified into four categories as shown in Table 7.

Table 7: Classification of irrigation water based on salinity (EC) values

| **Level** | **EC (µS/cm)** | **No. Of Samples** | **Hazard and limitations** |
|---|---|---|---|
| **C1** | < 250 | 0 | Low hazard; no detrimental effects on plants, and no soil build-up expected. |
| **C2** | 250 - 750 | 7 | Sensitive plants may show stress; moderate leaching prevents salt accumulation in soil. |
| **C3** | 750 - 2250 | 52 | Salinity will adversely affect most plants; requires selection of salt-tolerant plants, careful irrigation, good drainage, and leaching. |
| **C4** | > 2250 | 32 | Generally unacceptable for irrigation, except for very salt tolerant plants, excellent drainage, frequent leaching, and intensive management. |

Based on this classification, the most of samples were C2 water type (7 sample) with EC values between 250- 750 (µS/cm), while52 samples were C3 with EC 750 - 2250µS/cm) while32 samples were C4 with EC> 2250. These samples generally refer to unacceptable for irrigation, except on very salt tolerant plants with field conditions including, excellent drainage, frequent leaching, and intensive management.

# 6- Conclusions and recommendations

## 6-1 Conclusions

- The results of this study provide information that can be useful for the management of the groundwater resources in the lower part of Wadi Harad and Al Jar catchment area especially with respect to saltwater intrusion and its areas of influence.
- The groundwater quality of the study area has a primary problem of salinity followed by nitrate contamination which needs a special attention.
- Results indicate that, groundwater generally has pH >7, fresh to brackish water type and very hard.
- The abundance of the major ions is as follows: Na+1 > Ca+2 > Mg+2 > K+1 and Cl-1 > HCO3-1 > SO4-2 > NO3-1.
- The hydrochemical investigation indicates that groundwater in the study area is significantly modified as groundwater moves from the north-eastern (recharge areas) to the west.
- The water type evolve from low TDS, earth alkaline water with increased portions of alkalis with prevailing bicarbonate in the recharge areas to moderate and high TDS, alkaline water with prevailing sulfate and chloride along Red Sea coast in the western pars.
- The reverse ion exchange and sea water intrusion controls the groundwater chemistry along the Red Sea coast areas and few parts of the study area.
- Deterioration in groundwater quality from anthropogenic activities has resulted from saltwater intrusion along the coastal areas due to groundwater overpumping and extensive use of fertilizers and infiltration of sewage water.
- Salinity and nitrate contamination are the two major problems in the area, which is alarming considering the use of this water for drinking.
- The majority of samples of cluster I are characterized by high salinity hazard with low and medium sodium alkali hazard.
- The samples of cluster II are distributed between medium and high sodium hazard with very high salinity hazard.
- The samples of clusters III and IV are found in deep wells drilled in the Volcanic .

## 6-2 Recommendations

- It is hoped that this study will serve as a case study indicating the potential impacts of agricultural, sea water intrusion and land use activities on deterioration of groundwater quality.
- It is strongly advised to take up water management practices and are very essential in protecting the groundwater resources.
- Vulnerability assessment study is strongly recommended to evaluate management options in controlling the groundwater in the study area.
- Drilling of observation wells particularly in agricultural areas with continuous groundwater quality monitoring program seems to be very necessary.

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# Appendix (1): Technical staff who participated in the Study

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**Eng. Ghofran Ahmed Al Khail**

NWRA _ Sana'a Branch, Chemist

# Appendix (2): Water-points sampled, analyzed in the study area

| Sample No. | Well NO. | Site | Well Type | UTM East | UTM North | Total Depth (m) | Water Use |
|---|---|---|---|---|---|---|---|
| WQM 106 | A 971 | Dyer Al Hasy | Bore | 297958 | 1775291 | 72 | Supply |
| WQM 107 | A 964 | Bani Labnyh | Bore | 295591 | 1774710 | 70 | Supply |
| WQM 108 | A 955 | Village Al Sokef | Bore | 292916 | 1775651 | 100 | Supply |
| WQM 109 | E 858 | Abs | Bore | 303154 | 1776749 | 45 | Industry |
| WQM 110 | E 854 | Project Village Al Ak | Bore | 305126 | 1777372 | 130 | Supply |
| WQM 111 | E 765 | Al Jar | Bore | 288616 | 1775939 | 100 | Irrigation |
| WQM 112 | E804 | Al Galahef | Bore | 288150 | 1779846 | 100 | Supply |
| WQM 113 | B 867 | Al Jar | Bore | 282386 | 1776082 | 80 | Irrigation |
| WQM 114 | B 842 | Al Jar | Bore | 279023 | 1776287 | 100 | Irrigation |
| WQM 115 | B 1045 | Bani Al Masat | Dug | 307664 | 1764348 | 15 | Irrigation |
| WQM 116 | B 982 | Al Akabh | Dug | 310802 | 1767707 | 6 | Tankers |
| WQM 117 | E 907 | Jabal Al Menyh | Dug | 311566 | 1774327 | 15 | Irrigation |
| WQM 118 | A 1004 | bahrah | Bore | 304667 | 1770250 | 70 | Supply |
| WQM 120 | C 837 | Al ◌ً Village Dyer Wajrah+ khmah | Bore | 294884 | 1769539 | 110 | Supply |
| WQM 121 | A 927 | Abs | Bore | 288203 | 1768491 | 140 | Supply |
| WQM 122 | C 798 | Al Jar | Bore | 283365 | 1769417 | 100 | Irrigation |
| WQM 123 | C 737 | Al Jar | Bore | 279064 | 1769965 | 105 | Irrigation |
| WQM 124 | C 664 | Al harajh | Bore | 275562 | 1768384 | 40 | Irrigation |
| WQM 125 | E 712 | Al Jar | Bore | 285157 | 1774953 | 100 | Irrigation |
| WQM 126 | E 935 | Al Makzan | Bore | 301265 | 1783528 | 45 | Irrigation+Tankers |
| WQM 127 | B 888 | Al Jar | Bore | 284549 | 1779417 | 100 | Irrigation |
| WQM 128 | B 834 | Al Jar | Bore | 276554 | 1774950 | 53 | Irrigation |
| WQM 129 | C 842 | Village Lebadh | Bore | 297058 | 1765689 | 60 | Domestic |
| WQM 130 | C 810 | Sab Al Ashr | Bore | 281130 | 1762496 | 100 | Irrigation |
| WQM 131 | C 804 | Haraght Bani Keladh | Bore | 276753 | 1763076 | 42 | Irrigation |
| WQM 132 | B 897 | Al Tenah | Bore | 274748 | 1785000 | 30 | Irrigation |
| WQM 134 | B 906 | Al Tenah | Bore | 277795 | 1784538 | 42 | Irrigation |
| WQM 135 | B 970 | Al Tenah | Bore | 281648 | 1785905 | 100 | Supply |
| WQM 136 | E 951 | Bani Hasan | Bore | 299047 | 1783541 | 53 | Irrigation |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| WQM 137 | C 838 | Kadf Al Mahrah | Bore | 289264 | 1763967 | 87 | Supply |
| WQM 139 | D 1152 | Al Mhsam | Dug | 302732 | 1786203 | 30 | Domestic |
| WQM 140 | D 1124 | Al Rabay Wadi Habl | Dug | 306336 | 1787837 | 6 | Irrigation |
| WQM 141 | E969 | Al Donh Project Village | Bore | 296108 | 1784083 | 70 | Supply |
| WQM 142 | E990 | Al Kadef Al Sager | Bore | 292508 | 1783173 | 70 | Irrigation |
| WQM 143 | E 1044 | Al Mandarh | Bore | 285576 | 1784453 | 100 | Irrigation |
| WQM 144 | E 1040 | Al Korah | Dug/Bore | 290138 | 1786906 | 75 | Irrigation |
| WQM 145 | F 491 | Bani Al Akoa | Bore | 295500 | 1789853 | 60 | Supply |
| WQM 146 | E1028 | Village Al Kaomh | Bore | 297400 | 1789526 | 85 | Domestic |
| WQM 147 | D 1140 | Dos Saib Al | Dug | 299236 | 1791062 | 23 | Domestic |
| WQM 148 | F 544 | Bani Al Zain | Bore | 290967 | 1796075 | 85 | Irrigation |
| WQM 149 | F562 | Rofsh | Bore | 288594 | 1792583 | 70 | Irrigation |
| WQM 150 | F 633 | Al Gedyh | Bore | 280623 | 1792344 | 60 | Irrigation |
| WQM 151 | F502 | Dyer Ali Abkr | Dug/Bore | 292290 | 1790612 | 90 | Irrigation |
| WQM 152 | F533 | Sadh Al | Bore | 292748 | 1799543 | 65 | Supply |
| WQM 153 | F 708 | Bani Fadel | Bore | 285880 | 1798840 | 50 | Irrigation |
| WQM 154 | B 1613 | Bani Makay | Bore | 283674 | 1800363 | 65 | Irrigation |
| WQM 155 | F671 | Al Sorah | Bore | 278178 | 1796164 | 42 | Irrigation |
| WQM 156 | F662 | Bani Faed | Bore | 275906 | 1798107 | 36 | Irrigation |
| WQM 157 | F 556 | Bani Al Zayn and Bani Fadel | Bore | 289427 | 1799835 | 90 | Supply |
| WQM 158 | D 1251 | Al Asar | Dug | 302080 | 1792437 | 12 | Domestic |
| WQM 159 | D 1227 | Al Kaherh | Dug | 309740 | 1794103 | 10 | Irrigation |
| WQM 160 | D 1186 | Village Alawy | Dug | 303028 | 1800402 | 10 | Irrigation |
| WQM 161 | D 1169 | Al Awga Village | Bore | 300210 | 1800497 | 50 | Supply |
| WQM 162 | D 1263 | Al Msarekh | Dug | 298204 | 1801841 | 27 | Irrigation |
| WQM 163 | D 1293 | Al Farsh | Dug | 306252 | 1803085 | 12 | Domestic |
| WQM 164 | D 1308 | A l Tanakebh | Dug | 299885 | 1804328 | 30 | Irrigation |
| WQM 165 | D 1337 | Village Al Ten | Bore | 296296 | 1806523 | 54 | Domestic |
| WQM 166 | F 594 | Al Glahef | Dug/Bore | 294287 | 1803347 | 49 | Irrigation |
| WQM 167 | F 739 | Al SAbateh | Bore | 292788 | 1808772 | 110 | Irrigation |
| WQM 168 | A 1048 | Al Karash | Dug/Bore | 294367 | 1811996 | 60 | Irrigation |
| WQM 169 | D 1388 | Village Al Karsh | Dug | 298774 | 1814142 | 20 | Domestic |
| WQM 170 | D 1386 | Al Matared | Dug | 298545 | 1810418 | 15 | Irrigation |
| WQM 171 | C 1120 | SAfan | Bore | 290774 | 1812261 | 75 | Irrigation |
| WQM 172 | C 1037 | Village Al Hegarh | Bore | 288047 | 1811665 | 75 | Supply |
| WQM 173 | F774 | Al Kas | Dug/Bore | 286686 | 1808772 | 83 | Irrigation |
| WQM 174 | B 1644 | Al Saib | Bore | 284358 | 1808121 | 75 | Irrigation |
| WQM 175 | B 1507 | Al Makasen | Bore | 275304 | 1806801 | 35 | Irrigation |
| WQM 176 | B 1517 | Al Makasen | Bore | 277680 | 1806623 | 58 | Irrigation |

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|---|---|---|---|---|---|---|---|
| WQM 177 | B 1606 | Al Kdra | Bore | 281752 | 1804985 | 75 | Irrigation |
| WQM 178 | B 1573 | Al Kdra | Bore | 277276 | 1801947 | 33 | Irrigation |
| WQM 179 | B 1559 | Al Mosalem | Bore | 280068 | 1800955 | 50 | Irrigation |
| WQM 180 | C 985 | Al Aselh | Bore | 289030 | 1815077 | 42 | Supply |
| WQM 181 | C1001 | Al Ozela Village | Bore | 285253 | 1813696 | 80 | Irrigation |
| WQM 182 | B 1406 | Al Kdra Project Village | Bore | 282309 | 1810786 | 120 | Supply |
| WQM 183 | B 1417 | Al Kdra | Bore | 279908 | 1809218 | 60 | Irrigation |
| WQM 184 | A 1166 | Harad | Bore | 293027 | 1815299 | 65 | Supply |
| WQM 185 | A1158 | Zahb Al Hager | Dug/Bore | 295848 | 1816808 | 60 | Irrigation |
| WQM 186 | C 865 | Kadf Al Mtgrh | Bore | 290729 | 1817517 | 35 | Irrigation |
| WQM 187 | F847 | Al Mger | Dug/Bore | 288727 | 1822327 | 63 | Domestic |
| WQM 188 | A 1373 | Gomrak Harad | Bore | 286024 | 1824386 | 70 | Supply |
| WQM 189 | D 1398 | Al Hoseah | Bore | 291054 | 1823406 | 75 | Irrigation |
| WQM 190 | F 510 | Bani Al Mash | Bore | 292290 | 1794991 | 35 | Supply |
| WQM 191 | B 1468 | Al Makasen | Bore | 273494 | 1809315 | 40 | Irrigation |
| WQM 192 | B 1448 | Mtan | Bore | 276311 | 1811080 | 60 | Irrigation |
| WQM 193 | B 1364 | Mtan | Bore | 280751 | 1813938 | 80 | Irrigation |
| WQM 194 | C 929 | Project Village Mahfodh | Dug/Bore | 286103 | 1818110 | 55 | Domestic |
| WQM 196 | A 1316 | Al Srafeh | Bore | 292543 | 1819851 | 40 | Irrigation |
| WQM 197 | D 1391 | Am Al Hasm | Bore | 298774 | 1822182 | 100 | Irrigation |
| WQM 198 | A 1246 | Al Kafl | Bore | 299334 | 1820291 | 30 | Supply |
| WQM 199 | D 1381 | Al Sagen | Dug | 303631 | 1807401 | 21 | Supply |
| WQM 200 | A 924 | Daod - Abs | Bore | 290432 | 1769061 | 108 | Supply |

## Appendix (3): physical and chemical characteristics of the studied samples

| Sample No | EC µS/cm | pH | T | TDS mg/L | TH mg/L | $HCO_3$ mg/L | Cl mg/L | $SO_4$ mg/L | F mg/L | Ca mg/L | Mg mg/L | Na mg/L | K mg/L | Nitrate mg/L | Fe mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WQM-106 | 2060 | 7 | 33 | 1339 | 421 | 140 | 411 | 325 | 2 | 104 | 39 | 291 | 10 | 10 | 0 |
| WQM-107 | 2500 | 7 | 36 | 1625 | 899 | 205 | 559 | 290 | 0 | 233 | 77 | 179 | 5 | 32 | 0 |
| WQM-108 | 2850 | 7 | 35 | 1852.5 | 957 | 202 | 611 | 370 | 1 | 240 | 87 | 251 | 5 | 21 | 0 |
| WQM-109 | 1844 | 7 | 35 | 1198.6 | 494 | 275 | 285 | 335 | 1 | 118 | 48 | 235 | 4 | 29 | 0 |
| WQM-110 | 1324 | 7 | 35 | 860.6 | 335 | 285 | 150 | 170 | 1 | 80 | 33 | 172 | 3 | 42 | 0 |
| WQM-111 | 2520 | 7 | 37 | 1638 | 752 | 202 | 549 | 280 | 1 | 175 | 77 | 257 | 4 | 78 | 0 |
| WQM-112 | 2750 | 8 | 33 | 1787.5 | 604 | 184 | 590 | 265 | 1 | 149 | 56 | 353 | 6 | 42 | 0 |
| WQM-113 | 1891 | 8 | 34 | 1229.2 | 574 | 171 | 380 | 250 | 0 | 129 | 61 | 174 | 4 | 21 | 1 |
| WQM-114 | 1720 | 8 | 37 | 1118 | 474 | 159 | 330 | 175 | 0 | 86 | 63 | 162 | 4 | 51 | 0 |
| WQM-115 | 1422 | 7 | 33 | 924.3 | 456 | 450 | 158 | 115 | 0 | 100 | 50 | 130 | 4 | 15 | 0 |
| WQM-116 | 1032 | 8 | 28 | 670.8 | 220 | 239 | 124 | 125 | 0 | 42 | 28 | 123 | 10 | 4 | 0 |
| WQM-117 | 1963 | 7 | 31 | 1276 | 527 | 485 | 273 | 245 | 1 | 99 | 68 | 245 | 3 | 27 | 0 |
| WQM-118 | 1549 | 7 | 31 | 1006.9 | 415 | 269 | 266 | 155 | 0 | 97 | 42 | 160 | 4 | 15 | 0 |
| WQM-120 | 1414 | 7 | 36 | 919.1 | 421 | 219 | 241 | 155 | 0 | 91 | 47 | 128 | 4 | 36 | 1 |
| WQM-121 | 1540 | 7 | 38 | 1001 | 500 | 211 | 278 | 115 | 0 | 109 | 55 | 116 | 3 | 88 | 0 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WQM-122 | 1179 | 7 | 40 | 766.4 | 349 | 218 | 174 | 95 | 0 | 61 | 47 | 101 | 3 | 62 | 0 |
| WQM-123 | 1229 | 8 | 38 | 798.9 | 333 | 151 | 221 | 70 | 0 | 60 | 44 | 120 | 3 | 86 | 0 |
| WQM-124 | 7440 | 7 | 36 | 4836 | 1947 | 111 | 1986 | 275 | 1 | 312 | 284 | 786 | 7 | 640 | 0 |
| WQM-125 | 1977 | 7 | 38 | 1285.1 | 620 | 209 | 448 | 210 | 0 | 141 | 65 | 178 | 3 | 38 | 0 |
| WQM-126 | 997 | 7 | 34 | 648.1 | 276 | 205 | 146 | 95 | 0 | 58 | 32 | 99 | 1 | 16 | 0 |
| WQM-127 | 2290 | 7 | 37 | 1488.5 | 573 | 278 | 442 | 275 | 0 | 116 | 69 | 276 | 6 | 18 | 0 |
| WQM-128 | 3460 | 7 | 37 | 2249 | 901 | 108 | 906 | 195 | 0 | 176 | 112 | 357 | 6 | 99 | 0 |
| WQM-129 | 3270 | 7 | 31 | 2125.5 | 601 | 209 | 751 | 275 | 1 | 114 | 77 | 450 | 6 | 40 | 0 |
| WQM-130 | 1381 | 8 | 36 | 897.7 | 172 | 194 | 281 | 90 | 1 | 28 | 25 | 230 | 4 | 10 | 0 |
| WQM-131 | 3760 | 8 | 34 | 2444 | 625 | 157 | 989 | 275 | 0 | 97 | 93 | 517 | 5 | 16 | 0 |
| WQM-132 | 11620 | 7 | 33 | 7553 | 3172 | 115 | 3533 | 800 | 1 | 565 | 427 | 1396 | 7 | 299 | 0 |
| WQM-134 | 4470 | 8 | 35 | 2905.5 | 1001 | 149 | 916 | 770 | 0 | 192 | 126 | 598 | 4 | 112 | 0 |
| WQM-135 | 1380 | 8 | 37 | 897 | 322 | 210 | 231 | 125 | 1 | 64 | 39 | 160 | 3 | 55 | 0 |
| WQM-136 | 1521 | 8 | 36 | 988.7 | 420 | 230 | 292 | 140 | 1 | 89 | 48 | 151 | 1 | 23 | 0 |
| WQM-137 | 2220 | 8 | 36 | 1443 | 433 | 182 | 549 | 240 | 0 | 91 | 50 | 307 | 5 | 40 | 0 |
| WQM-139 | 3000 | 8 | 35 | 1950 | 580 | 279 | 659 | 290 | 1 | 116 | 70 | 408 | 5 | 58 | 0 |
| WQM-140 | 3640 | 7 | 31 | 2366 | 536 | 340 | 742 | 400 | 1 | 104 | 67 | 598 | 5 | 12 | 0 |
| WQM-141 | 1470 | 7 | 37 | 955.5 | 438 | 388 | 226 | 98.5 | 0 | 105 | 42 | 149 | 1 | 15 | 0 |
| WQM-142 | 1507 | 7 | 38 | 979.6 | 356 | 251 | 272 | 130 | 0 | 69 | 45 | 183 | 2 | 23 | 0 |
| WQM-143 | 2170 | 7 | 39 | 1410.5 | 606 | 170 | 472 | 235 | 1 | 120 | 74 | 248 | 3 | 42 | 0 |
| WQM-144 | 1964 | 7 | 36 | 1276.6 | 513 | 234 | 446 | 152.5 | 0 | 107 | 60 | 236 | 2 | 22 | 0 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WQM-145 | 588 | 7 | 35 | 382.2 | 171 | 251 | 40 | 23 | 0 | 33 | 21 | 67 | 2 | 11 | 0 |
| WQM-146 | 1181 | 8 | 36 | 767.7 | 223 | 390 | 150 | 48 | 1 | 35 | 33 | 181 | 2 | 22 | 0 |
| WQM-147 | 654 | 8 | 30 | 425.1 | 263 | 265 | 40 | 42 | 0 | 61 | 27 | 34 | 1 | 23 | 0 |
| WQM-148 | 5920 | 7 | 31 | 3848 | 1436 | 145 | 1464 | 410 | 0 | 310 | 161 | 689 | 5 | 392 | 0 |
| WQM-149 | 1037 | 7 | 37 | 674.1 | 248 | 238 | 167 | 53 | 0 | 52 | 29 | 120 | 2 | 14 | 0 |
| WQM-150 | 1780 | 7 | 37 | 1157 | 412 | 174 | 432 | 90 | 1 | 81 | 51 | 228 | 3 | 39 | 0 |
| WQM-151 | 881 | 8 | 37 | 572.7 | 194 | 322 | 83 | 32 | 1 | 39 | 23 | 132 | 1 | 29 | 0 |
| WQM-152 | 1896 | 7 | 35 | 1232.4 | 584 | 243 | 275 | 350 | 1 | 121 | 68 | 195 | 6 | 83 | 0 |
| WQM-153 | 2070 | 7 | 35 | 1345.5 | 703 | 196 | 296 | 260 | 1 | 177 | 63 | 189 | 2 | 252 | 0 |
| WQM-154 | 2170 | 7 | 35 | 1410.5 | 724 | 113 | 530 | 150 | 0 | 180 | 67 | 171 | 7 | 58 | 0 |
| WQM-155 | 4850 | 7 | 35 | 3152.5 | 1544 | 134 | 1161 | 730 | 0 | 322 | 180 | 388 | 5 | 151 | 0 |
| WQM-156 | 5410 | 7 | 33 | 3516.5 | 1787 | 125 | 1148 | 650 | 1 | 369 | 210 | 479 | 4 | 304 | 0 |
| WQM-157 | 1614 | 7 | 36 | 1049.1 | 532 | 232 | 250 | 230 | 0 | 134 | 48 | 134 | 4 | 44 | 0 |
| WQM-158 | 2370 | 7 | 32 | 1540.5 | 1089 | 299 | 595 | 135 | 0 | 263 | 105 | 59 | 1 | 4 | 0 |
| WQM-159 | 1464 | 8 | 32 | 951.6 | 401 | 325 | 124 | 230 | 1 | 84 | 46 | 170 | 1 | 44 | 0 |
| WQM-160 | 3930 | 8 | 34 | 2554.5 | 641 | 377 | 711 | 620 | 1 | 109 | 90 | 639 | 2 | 62 | 0 |
| WQM-161 | 917 | 7 | 33 | 596.1 | 202 | 186 | 84 | 155 | 0 | 54 | 16 | 108 | 1 | 26 | 0 |
| WQM-162 | 1231 | 7 | 32 | 800.2 | 350 | 252 | 120 | 195 | 0 | 75 | 40 | 134 | 1 | 35 | 0 |
| WQM-163 | 2710 | 7 | 33 | 1761.5 | 588 | 401 | 453 | 395 | 1 | 118 | 71 | 394 | 2 | 29 | 0 |
| WQM-164 | 2950 | 7 | 34 | 1917.5 | 828 | 196 | 634 | 380 | 1 | 163 | 102 | 312 | 1 | 61 | 0 |
| WQM-165 | 3460 | 7 | 34 | 2249 | 980 | 210 | 760 | 430 | 1 | 193 | 121 | 361 | 1 | 61 | 0 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WQM-166 | 1573 | 7 | 35 | 1022.5 | 341 | 247 | 207 | 275 | 1 | 77 | 36 | 204 | 1 | 29 | 0 |
| WQM-167 | 3010 | 7 | 34 | 1956.5 | 745 | 234 | 685 | 280 | 1 | 162 | 83 | 344 | 2 | 70 | 0 |
| WQM-168 | 3490 | 7 | 37 | 2268.5 | 1029 | 238 | 784 | 285 | 1 | 230 | 111 | 336 | 3 | 74 | 0 |
| WQM-169 | 1753 | 7 | 33 | 1139.5 | 698 | 275 | 327 | 195 | 1 | 198 | 49 | 89 | 1 | 25 | 0 |
| WQM-170 | 7200 | 7 | 33 | 4680 | 2127 | 287 | 1856 | 867 | 1 | 526 | 198 | 770 | 2 | 82 | 0 |
| WQM-171 | 1249 | 7 | 35 | 811.9 | 339 | 219 | 148 | 155 | 1 | 82 | 32 | 134 | 4 | 42 | 0 |
| WQM-172 | 1295 | 7 | 35 | 841.8 | 337 | 229 | 135 | 170 | 1 | 74 | 37 | 143 | 4 | 63 | 0 |
| WQM-173 | 2240 | 7 | 36 | 1456 | 628 | 217 | 470 | 195 | 0 | 124 | 77 | 248 | 4 | 45 | 0 |
| WQM-174 | 2290 | 7 | 35 | 1488.5 | 610 | 182 | 505 | 160 | 0 | 124 | 73 | 248 | 5 | 76 | 0 |
| WQM-175 | 2820 | 8 | 33 | 1833 | 394 | 185 | 542 | 290 | 1 | 74 | 51 | 469 | 4 | 107 | 0 |
| WQM-176 | 1775 | 8 | 34 | 1153.8 | 414 | 200 | 269 | 175 | 1 | 81 | 51 | 223 | 3 | 130 | 0 |
| WQM-177 | 2420 | 8 | 36 | 1573 | 590 | 142 | 571 | 200 | 0 | 140 | 58 | 273 | 4 | 49 | 0 |
| WQM-178 | 9200 | 7 | 36 | 5980 | 2735 | 79 | 2807 | 375 | 1 | 599 | 301 | 919 | 9 | 279 | 0 |
| WQM-179 | 2990 | 8 | 37 | 1943.5 | 872 | 116 | 731 | 270 | 0 | 210 | 84 | 285 | 5 | 47 | 0 |
| WQM-180 | 696 | 8 | 34 | 452.4 | 210 | 210 | 36 | 90 | 1 | 48 | 22 | 62 | 3 | 40 | 0 |
| WQM-181 | 884 | 8 | 35 | 574.6 | 222 | 258 | 52 | 115 | 0 | 59 | 20 | 100 | 3 | 74 | 0 |
| WQM-182 | 1422 | 7 | 37 | 924.3 | 384 | 213 | 146 | 200 | 1 | 87 | 41 | 149 | 4 | 88 | 0 |
| WQM-183 | 1852 | 7 | 36 | 1203.8 | 499 | 180 | 289 | 215 | 1 | 116 | 51 | 191 | 4 | 95 | 0 |
| WQM-184 | 875 | 7 | 34 | 568.8 | 258 | 267 | 58 | 110 | 1 | 59 | 27 | 81 | 3 | 19 | 0 |
| WQM-185 | 953 | 7 | 31 | 619.5 | 295 | 272 | 80 | 130 | 0 | 76 | 25 | 79 | 4 | 12 | 0 |
| WQM-186 | 704 | 7 | 33 | 457.6 | 197 | 239 | 32 | 72 | 0 | 53 | 16 | 68 | 2 | 22 | 0 |

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| WQM-187 | 1322 | 6 | 37 | 859.3 | 394 | 283 | 155 | 150 | 0 | 109 | 29 | 124 | 3 | 20 | 0 |
| WQM-188 | 1703 | 7 | 33 | 1107 | 278 | 281 | 222 | 230 | 1 | 53 | 35 | 264 | 2 | 37 | 0 |
| WQM-189 | 1380 | 7 | 34 | 897 | 342 | 275 | 151 | 230 | 1 | 79 | 35 | 179 | 3 | 59 | 0 |
| WQM-190 | 1429 | 7 | 34 | 928.9 | 378 | 341 | 269 | 90 | 0 | 88 | 38 | 162 | 1 | 16 | 0 |
| WQM-191 | 4720 | 7 | 33 | 3068 | 1449 | 70 | 1108 | 483 | 1 | 294 | 173 | 423 | 8 | 376 | 0 |
| WQM-192 | 5530 | 7 | 36 | 3594.5 | 2050 | 83 | 1220 | 733 | 1 | 545 | 167 | 385 | 7 | 464 | 0 |
| WQM-193 | 1010 | 8 | 37 | 656.5 | 271 | 194 | 82 | 170 | 0 | 77 | 19 | 99 | 3 | 48 | 0 |
| WQM-194 | 826 | 8 | 36 | 536.9 | 185 | 213 | 72 | 110 | 0 | 49 | 15 | 100 | 3 | 22 | 0 |
| WQM-196 | 605 | 7 | 33 | 393.3 | 213 | 235 | 41 | 80 | 1 | 54 | 19 | 52 | 2 | 9 | 0 |
| WQM-197 | 2790 | 7 | 38 | 1813.5 | 1026 | 164 | 561 | 225 | 1 | 219 | 116 | 172 | 3 | 275 | 0 |
| WQM-198 | 724 | 7 | 34 | 470.6 | 195 | 210 | 45 | 115 | 1 | 53 | 16 | 64 | 5 | 6 | 0 |
| WQM-199 | 610 | 7 | 34 | 396.5 | 181 | 233 | 27 | 35 | 1 | 41 | 19 | 55 | 1 | 41 | 0 |
| WQM-200 | 1415 | 8 | 36 | 919.8 | 424 | 206 | 247 | 123 | 0 | 95 | 45 | 132 | 3 | 49 | 0 |