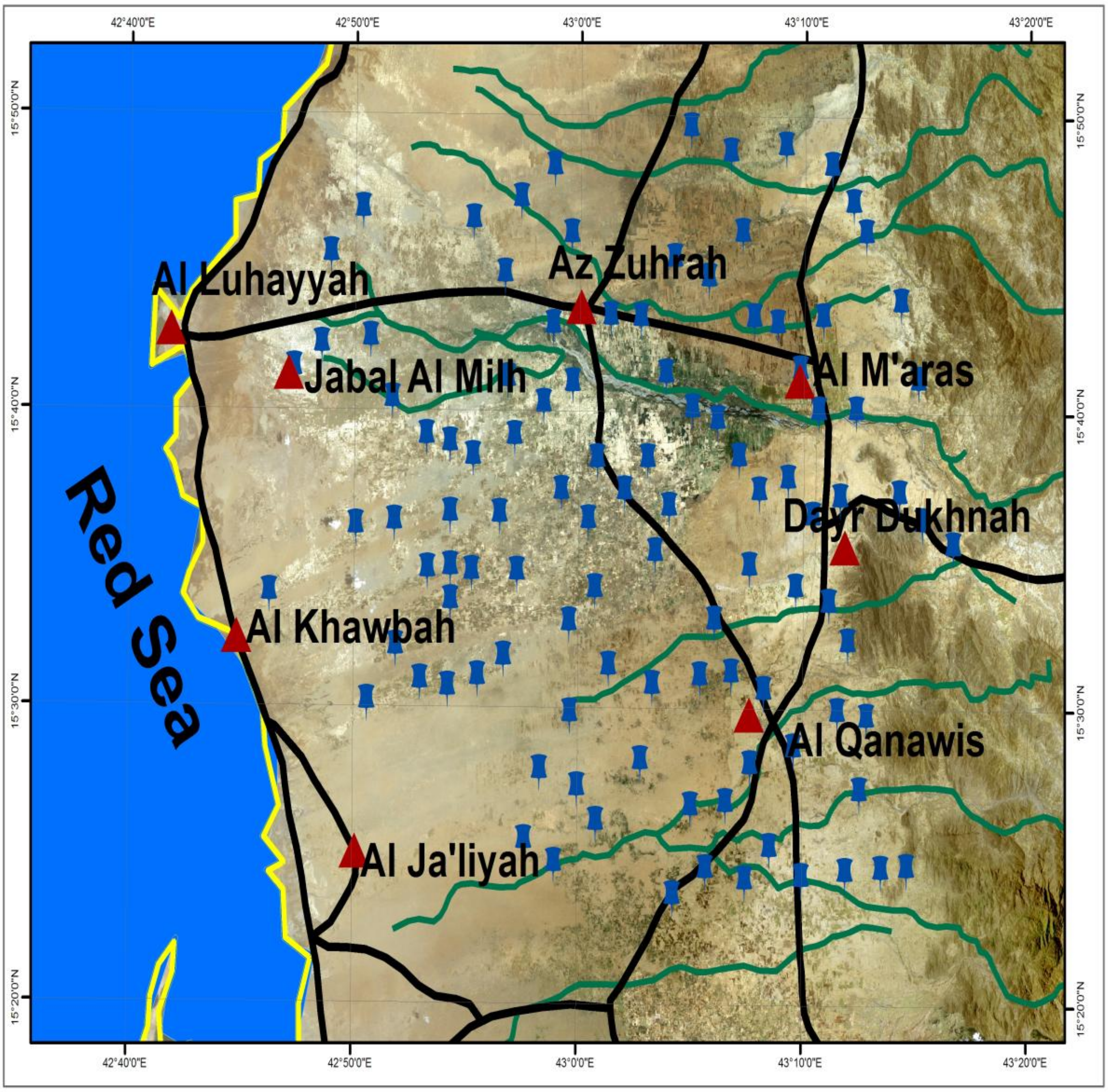
R E P U P L I C   OF   Y E M E N
Ministry Of Water and Environment
National Water Resource Authority
Studies and Planning Sector

TIHAMA WATER RESOURCES MANAGEMENT

Wadi Mawr Water Quality



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ABSTRACT

One hundred six groundwater samples were collected from Wadi Mawr 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 $Cl^{-1} > HCO_3^{-1} > SO_4^{-2} > NO_3^{-1}$. 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 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 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.

Keywords: Groundwater. Hydrogeochemical processes . Saltwater intrusion. Wadi Mawr 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.

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:

Wadi Mawr is one of the largest drainage systems of the Republic of Yemen with a catchments area of .about 8 000 km2. The Wadi emerges from the foothills to cross approximately 46 km of the Tihama coastal plain to the salt flats (sabkha) adjacent to the Red Sea. The project area lies between two smaller wadis, the Wadi Juah to the north and the Wadi Ayan to the south and has an average width of about 16 km. The Wadi Mawr divides the area into two almost equal parts. For the purposes of these groundwater studies, the area covered is considerably larger than the main project area as the hydro geological boundaries do not coincide with the project boundaries, and investigations were required to establish the northern and southern boundaries to the hydro geological regime.

The runoff from the catchments is sufficient to support a perennial surface flow for some distance west of the mountains with larger irregular spates occurring throughout the year. The diversion of both the base and flood flows into irrigation canals by the construction of temporary earth bunds across the wadi bed has been practiced for hundreds of years. Currently an area of some 15 000 ha is irrigated by this technique. Part of the present study has been concerned with the design and construction of a single permanent off take structure near the head of the wadi and two principal canals, one north and the other south of the wadi line to improve the use of the surface water resource.

The study area includes a large part of the Directorate of Al Munirah ,Al Qanawis, Alluheyah ,Az Zaydiyah and Az Zahrah directorates.

The total number of population in the study area is 411,111 people, according to population and housing census in 2004.

The area has an arid climate and is extremely hot except during the winter months of November through March when temperatures range from 26°C to about 34°C.

Mean monthly minimum temperatures range from about 19°C in December to 29°C in July; mean monthly maximum temperatures range from about 32°C in January to 40°C in June. The daily fluctuation of temperature is moderate.

Within the Wadi Mawr catchments area, annual rainfall generally decreases from southwest to northeast, ranging from 902 mm at Al Tur to about 221 mm at Bani Uwair in the northeastern portion of the catchments.

The Project Area is characterized by high humidity during the early morning hours in the summer months, lowering as the day progresses. Violent dust storms occur frequently in the afternoon, accompanied by high winds which are occasionally followed by heavy showers. The average relative humidity is 50 to 60 percent, ranging from 80 percent in the morning hours to 25 percent in late afternoons.

The mean daily evaporation from free water is 9 mm and ranges from 7 to 10.5 mm per day. The annual potential free water surface evaporation in the Wadi Mawr area is about 3,000 mm.

Figure 1: Location map of the study area.

1-4 Geology

The Tehama is a sediment-filled portion of the Red Sea grabber. A fault or fault zone trends north-south along the eastern border of the project where the streams emerge from the mountains onto the plain.

The mountains forming the eastern edge of the Project Area have not yet been geologically mapped, but are largely a complex of pre-Cambrian granites, diorites, syenites, and andacites; Jurrassic limestones and Tertiary intrusions are present, with many basic dikes. Several outliers of the mountains comprised largely of bosic dike materials, occur within the alluvial plain at the eastern border of the project. A very young salt dome is found at Gebel AI Milh in the western portion of the project, at which location a salt mine is presently operated.

This is the only known mineral deposit in the Project Area. The remainder of the area is underlain by alluvium derived from the mountains to the east.

The alluvium which constitutes the groundwater aquifer is largely comprised of silt, gravel, and sand. little clay has been encountered in drilling.

From the results of the drilling, it is difficult to correlate the sedimentary units with certainty. A high gravel terrace which is quite prominent just downstream of the confluence of Wadi La'ch and Wadi M.awr may be traceable into the subsurface of the Tihama. A coarse gravel, partially cemented in places, lies within about one meter of the surface in the eastern portion of the Project Area. It appears that this gravel unit dips to the west under the more recent silts, sands, and gravelly materials.

The depth to the basement in the area is unknown. The presence of hot springs, of anomalously warm and highly mineralized groundwater, just to the east of the Project Area and the salt domes and basic dikes at the western and eastern extremities of the Project Area suggest a complex subsurface.

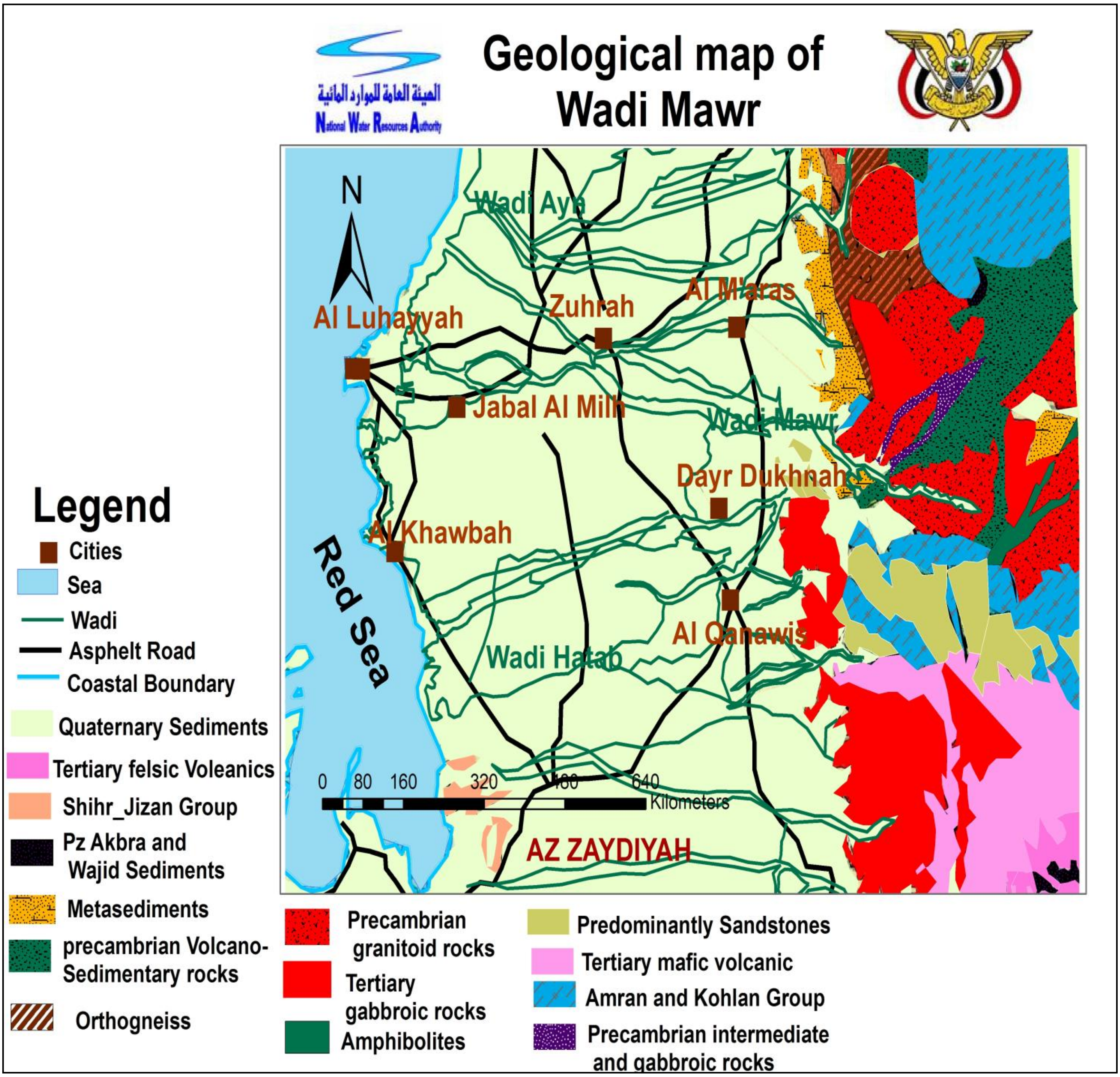


Figure2: Geological map of Wadi Mawr

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 North 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 Mawr

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 Mawr.

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:

1. 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).
2. There is information on pump depth and total depth for water points
3. The spatial distribution for samples from the Wadi
4. There is information on the geological structure for water points
5. 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 Haradh , 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) .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
Mawr	17	69	20	1	107

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).

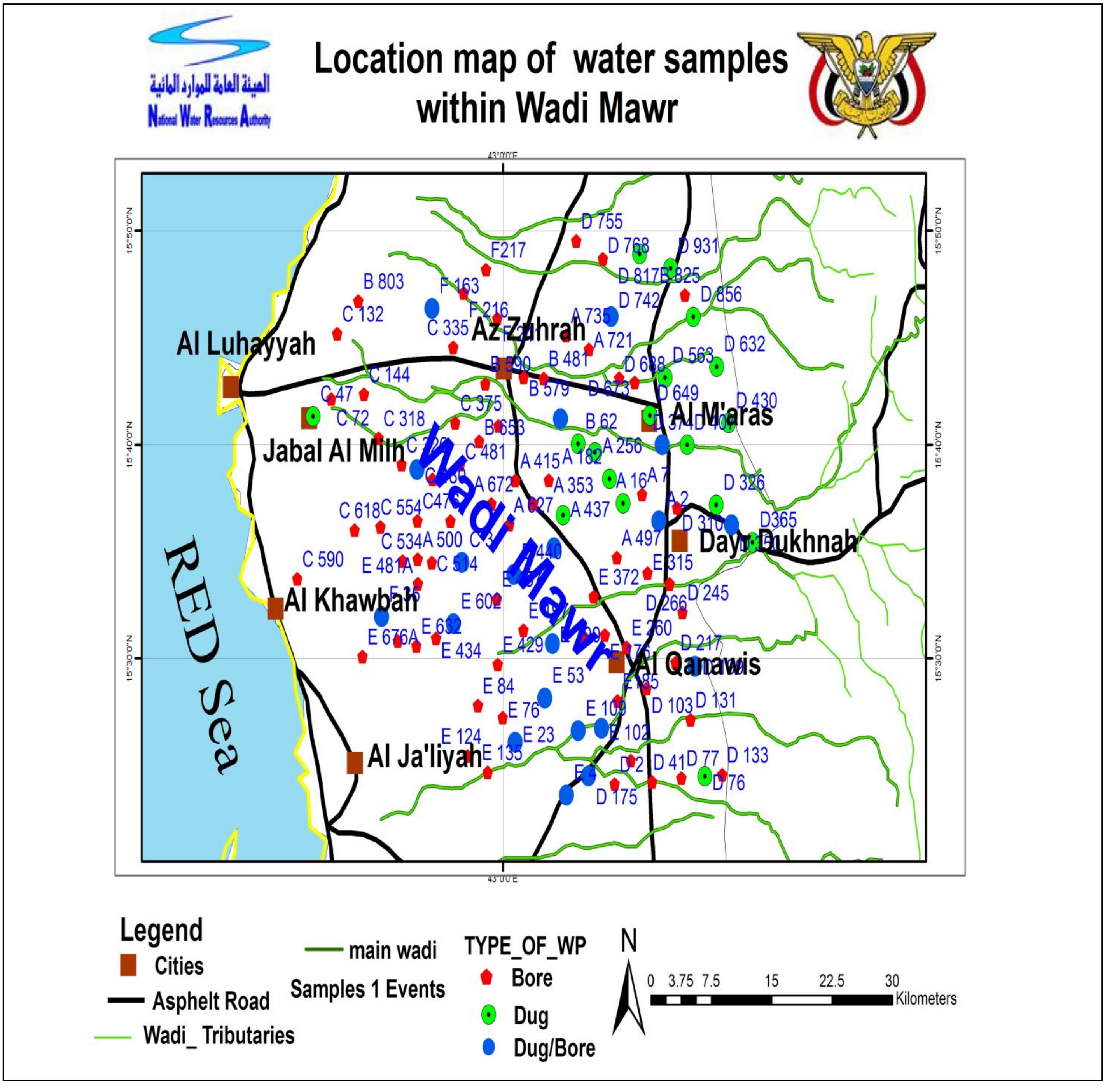


Figure 3: Location map of studied water samples within Wadi Mawr

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 e, electrical conductivity, pH, DO, and temperature.

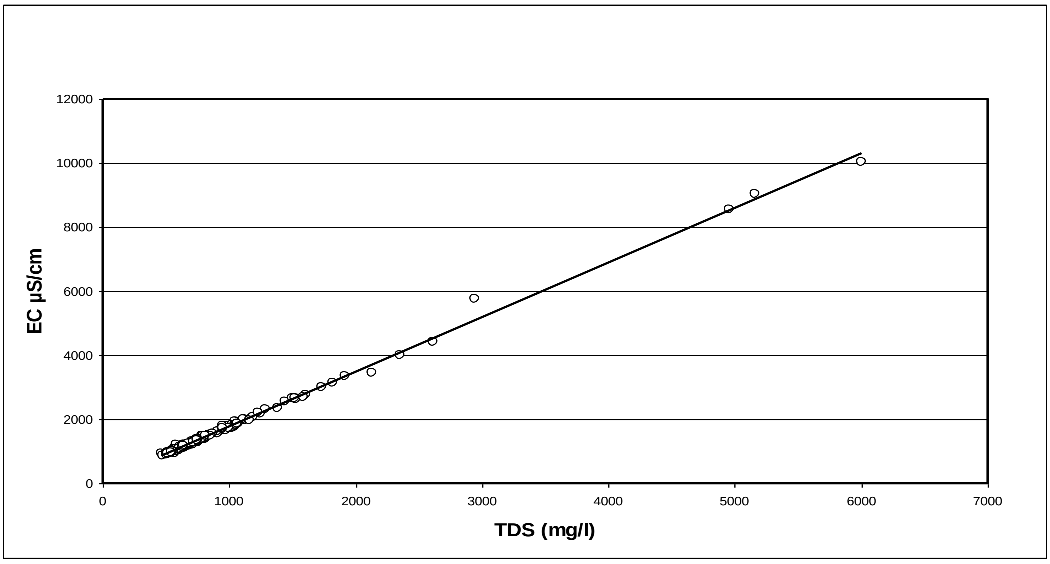
Electrical conductivity (EC):

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 varies between 907µS/cm and 11,650 µS/cm in Wadi Mawr with an average of 3216 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 Mawr plain in quaternary aquifer system is fresh water excepting the western part, which outlined to the west of Al Khawbah to Jabal Al Milh and Al Luhayyah where the fresh water overlain by shallow brackish groundwater. Some kilometers to the west groundwater become saline groundwater especially in direction to Jabal Al Milh and Al Luhayyah Peninsula northwest direction where sabkha is predominantly.

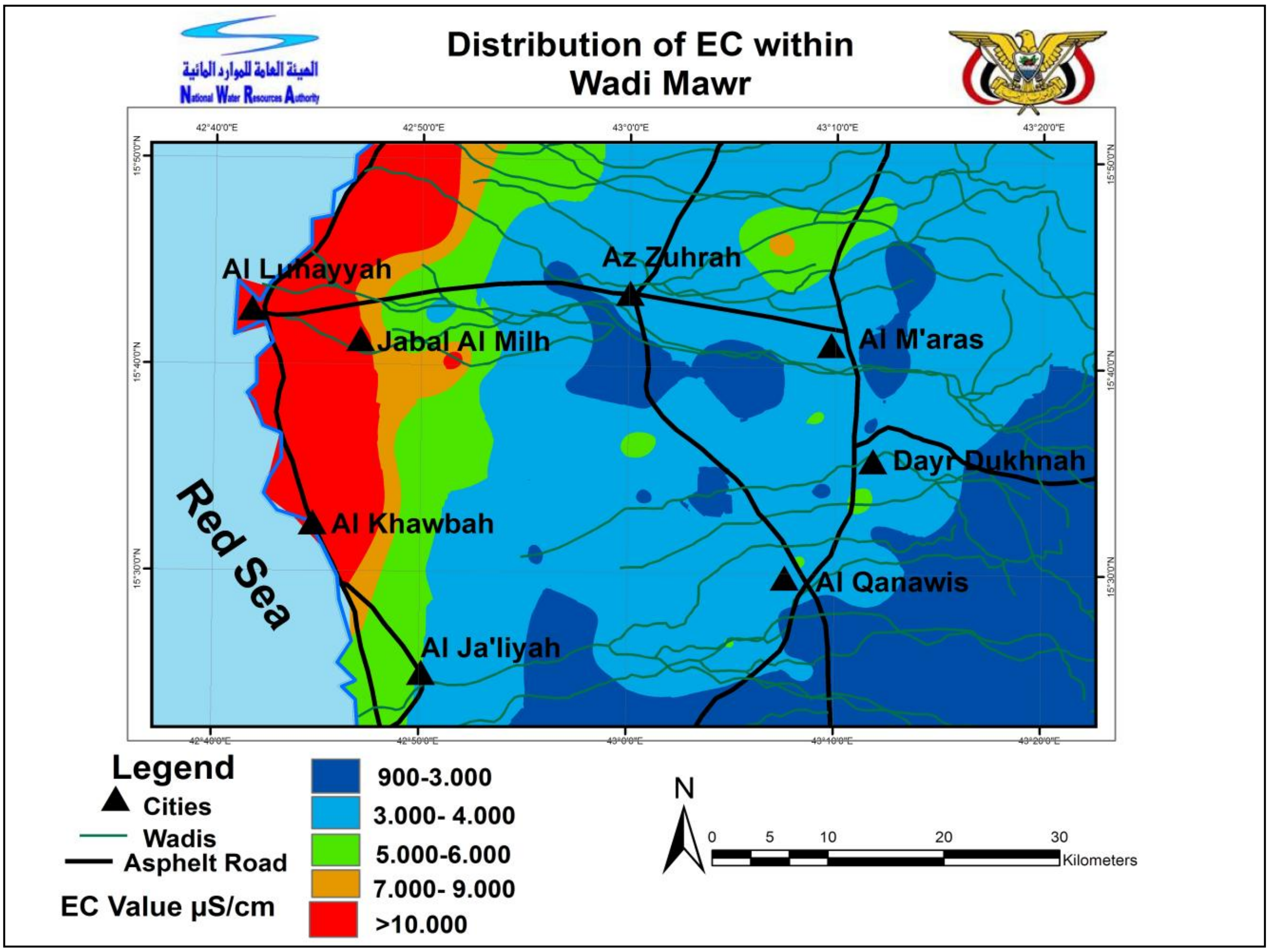


Figure 5: Distribution of Electrical Conductivity within Wadi Mawr

Hydrogen - Ion Concentration (pH):

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 Wadi Mawr, the pH values of groundwater samples range from 6.51 to 8.4 with an average value 7.2. 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.

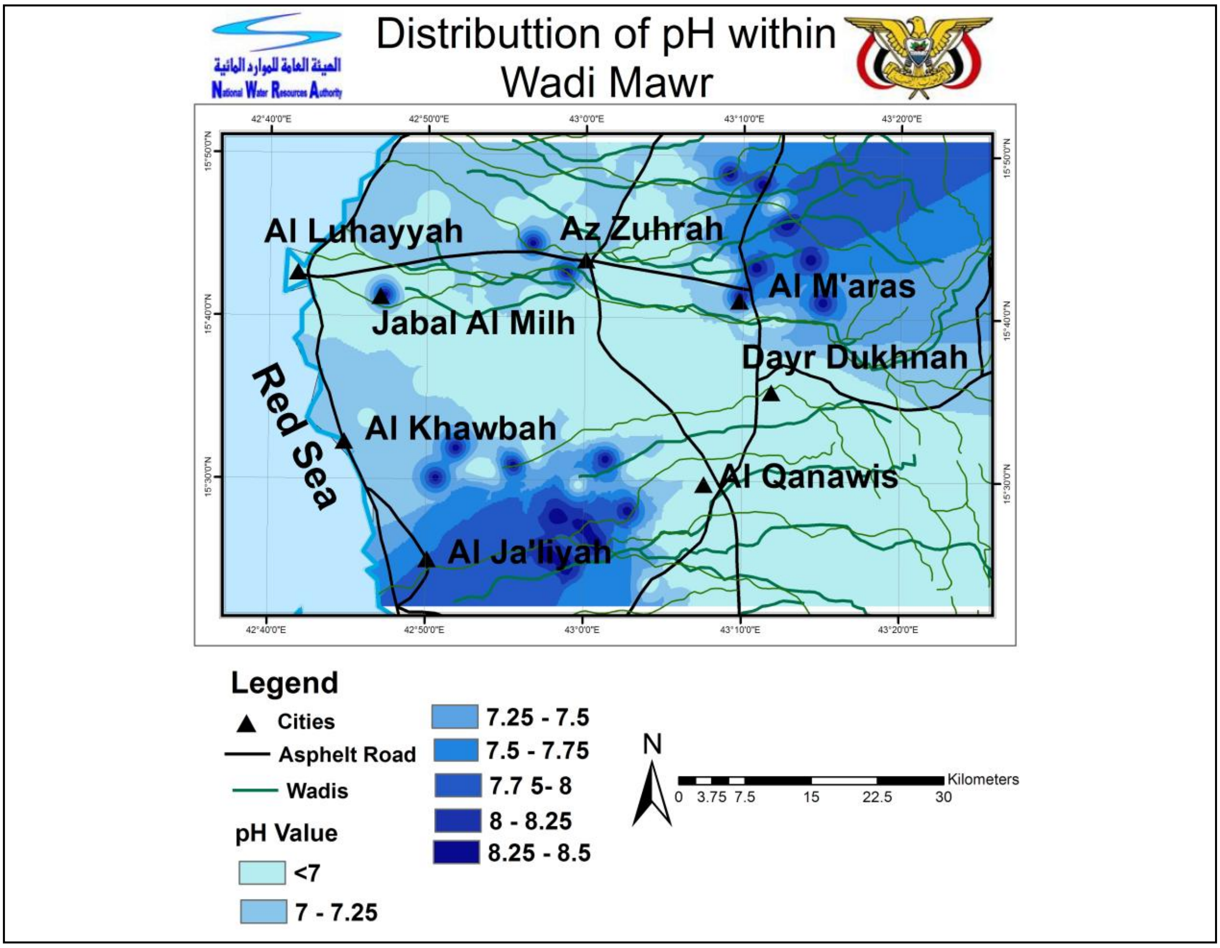


Figure 6: pH Distribution Within Wadi Mawr

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. For all water samples, temperature varied between 29 oC and 41.3 oC with average 34. 6 oC in Wadi Mawr.

Figure 7 clearly illustrates the distribution the temperature in the water samples. The high concentration trends are increase north- west and south - west of the area in Wadi Mawr.

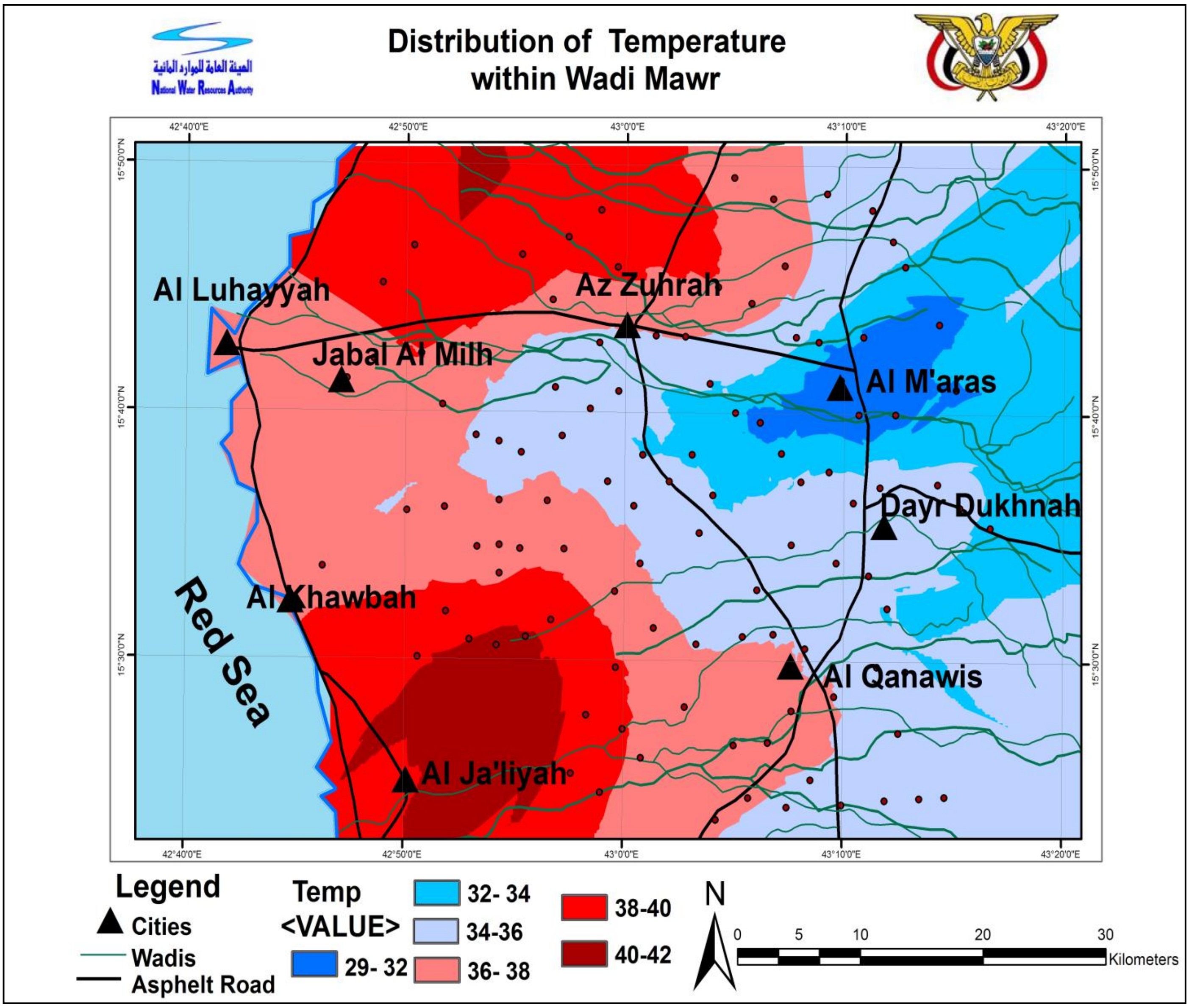


Figure 7: Temperature Distribution within Wadi Mawr

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 Mawr Samples are expressed in Appendix (3).

2-3-3-2 Quality of the analyses

The 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 Mawr , Calcium content ranges between 5 mg/l – 510 mg/l with average 154 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 Jabal Al Milh and south – east near from Dayr Dukhnah in Wadi Mawr.

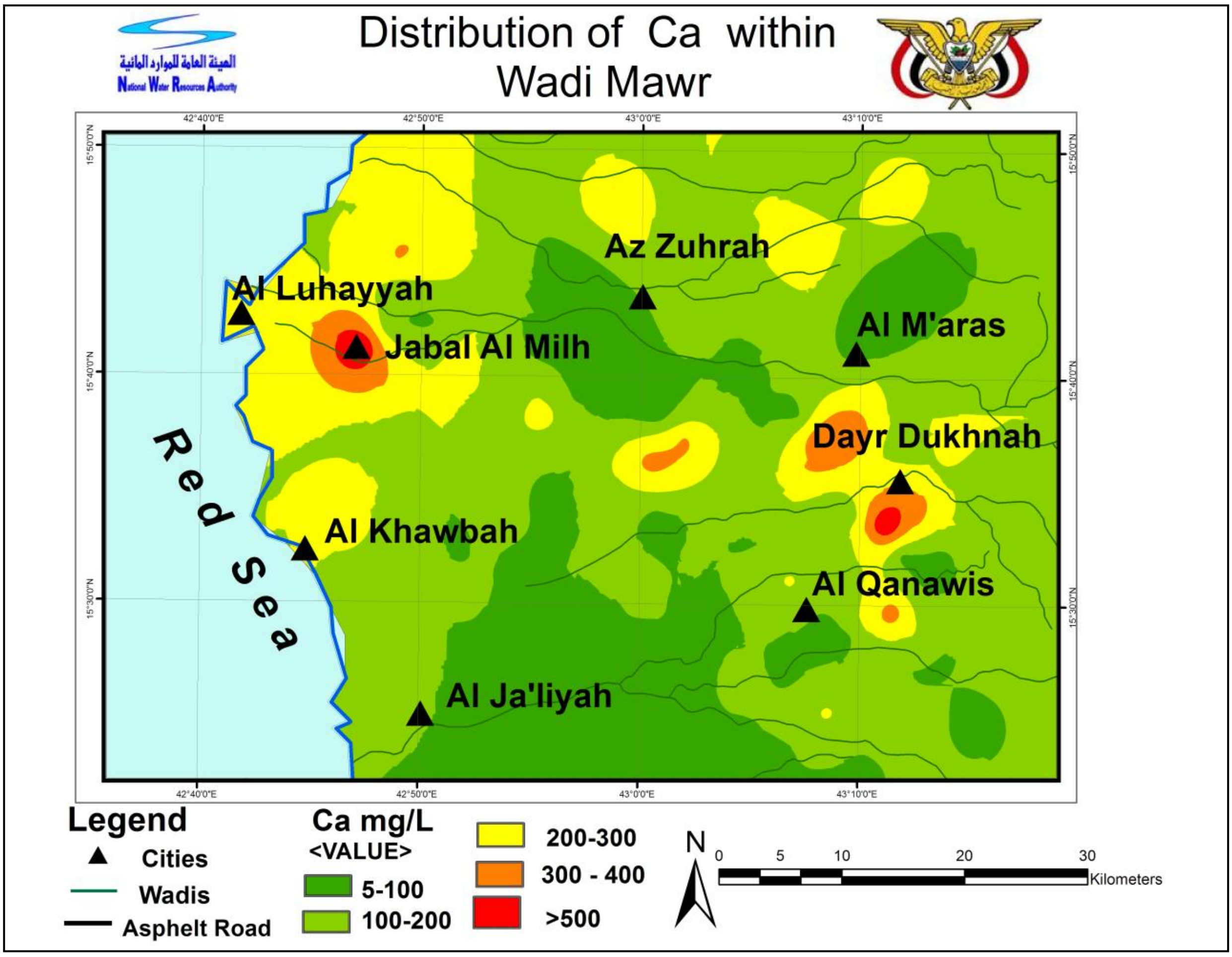


Figure 8: Calcium Concentration map in Wadi Mawr

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 Mawr , Magnesium content ranges between14 mg/l –374mg/ with average 114.5 mg/l .

Figure 9 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 Mawr.

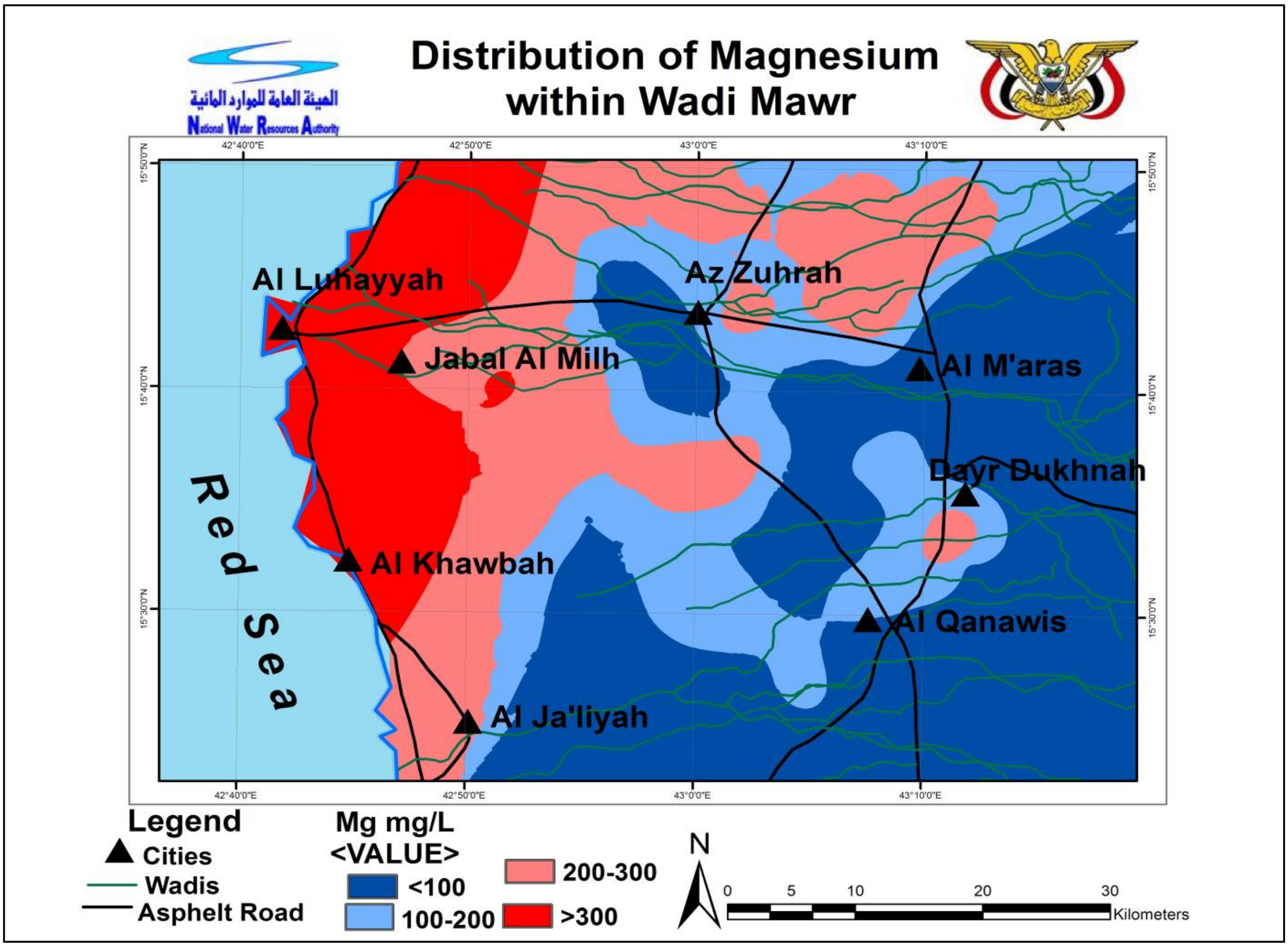


Figure9: Magnesium Concentration map in Wadi Mawr

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 Na_2SO_4 .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 Mawr, Sodium content ranges between89 mg/l – 2325 mg/l with average 414 mg/l .

Figure 10 clearly illustrates increasing sodium element on the west of Wadi Mawr and extended on the coast line to north-west near Al Khawbah.

The increase in 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 .

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 K_2SO_4. In the Wadi Mawr, potassium content ranges between 1.8 mg/l - 38.5 mg/l with average 7.24 mg/l .

Figure 11 Shows the distribution of the Potassium concentration in the western region in terms of increasing the proportion of salt water intrusion in the eastern regions where there are Volcanic as in the samples D931,D350.

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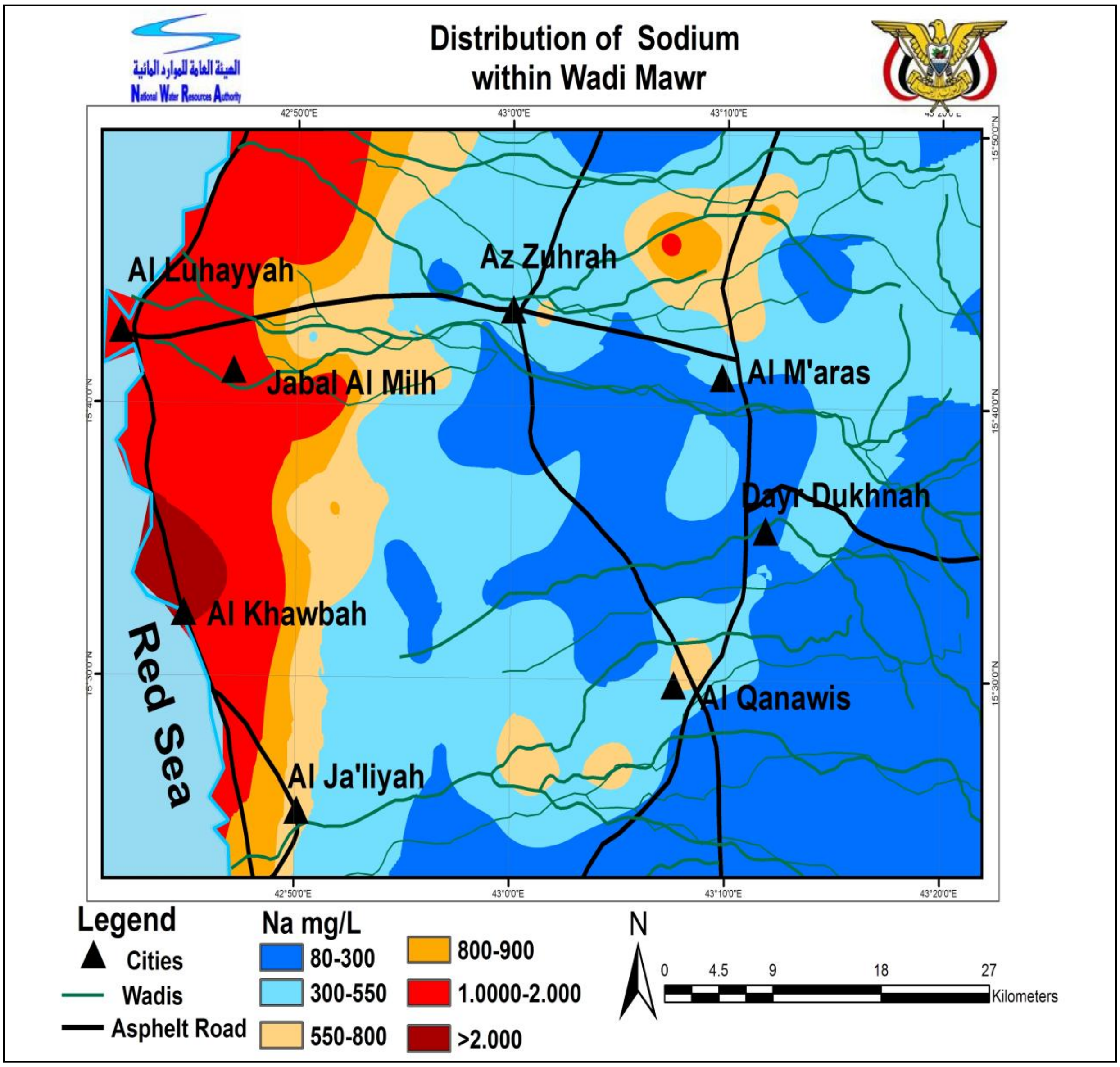

Figure 10: Sodium Concentration in Wadi Mawr

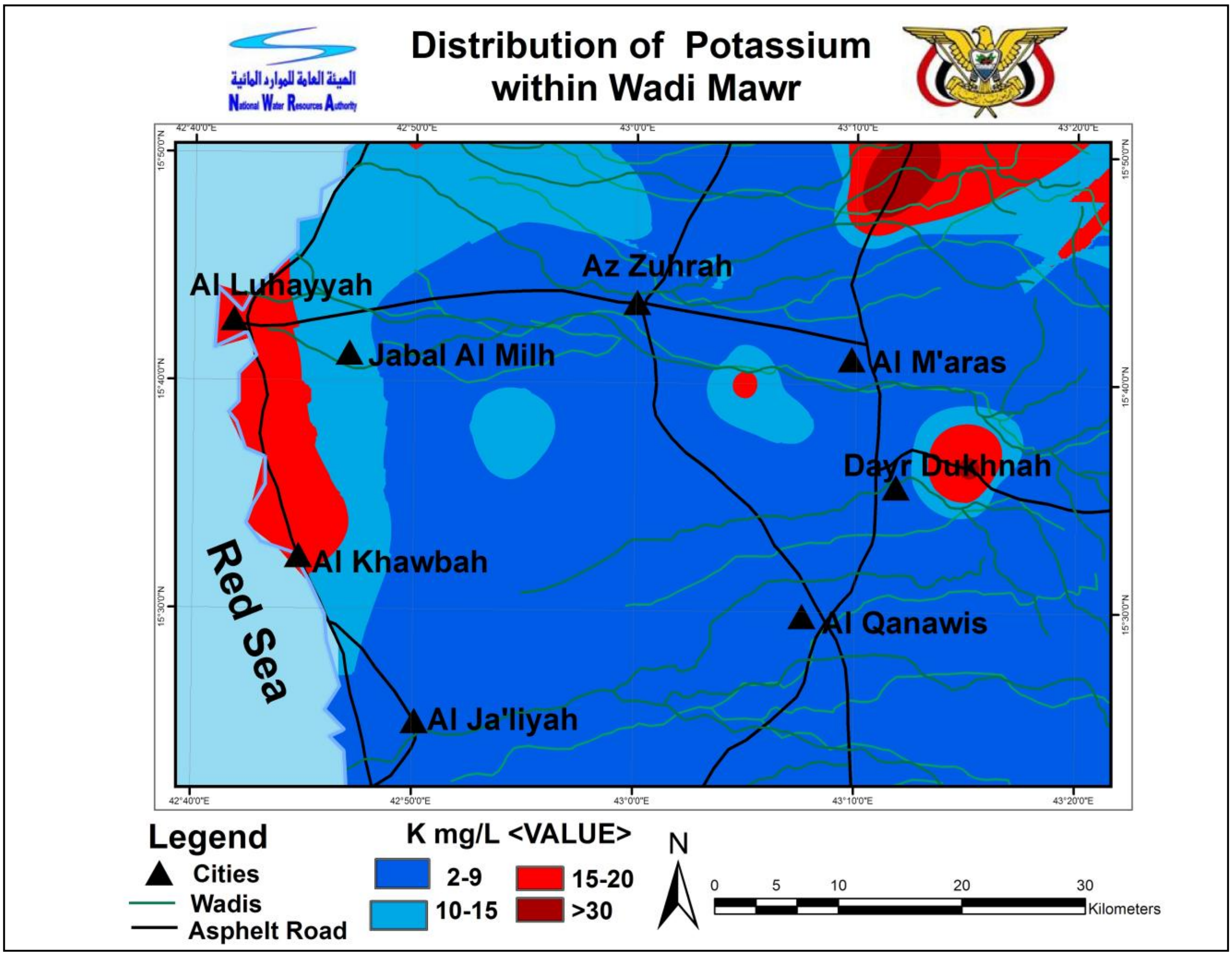

Figure 11: Potassium Concentration in Wadi Mawr

2- Major anions

Carbonate (CO_3^-) and Bicarbonate (HCO_3^-)

The main source of carbonate and bicarbonate is carbon- dioxide (CO_2) from the atmosphere. Carbon dioxide released within the soil by organic decay and from plant respiration. In Wadi Mawr carbonate was not found in any samples.

The concentration of bicarbonate in Wadi Mawr ranges between 101 mg/l – 1041 mg/l with average 287 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 north east of Wadi Mawr. The concentration map of bicarbonate shows the highest concentration in the north east parts , south east and the center of the study area.

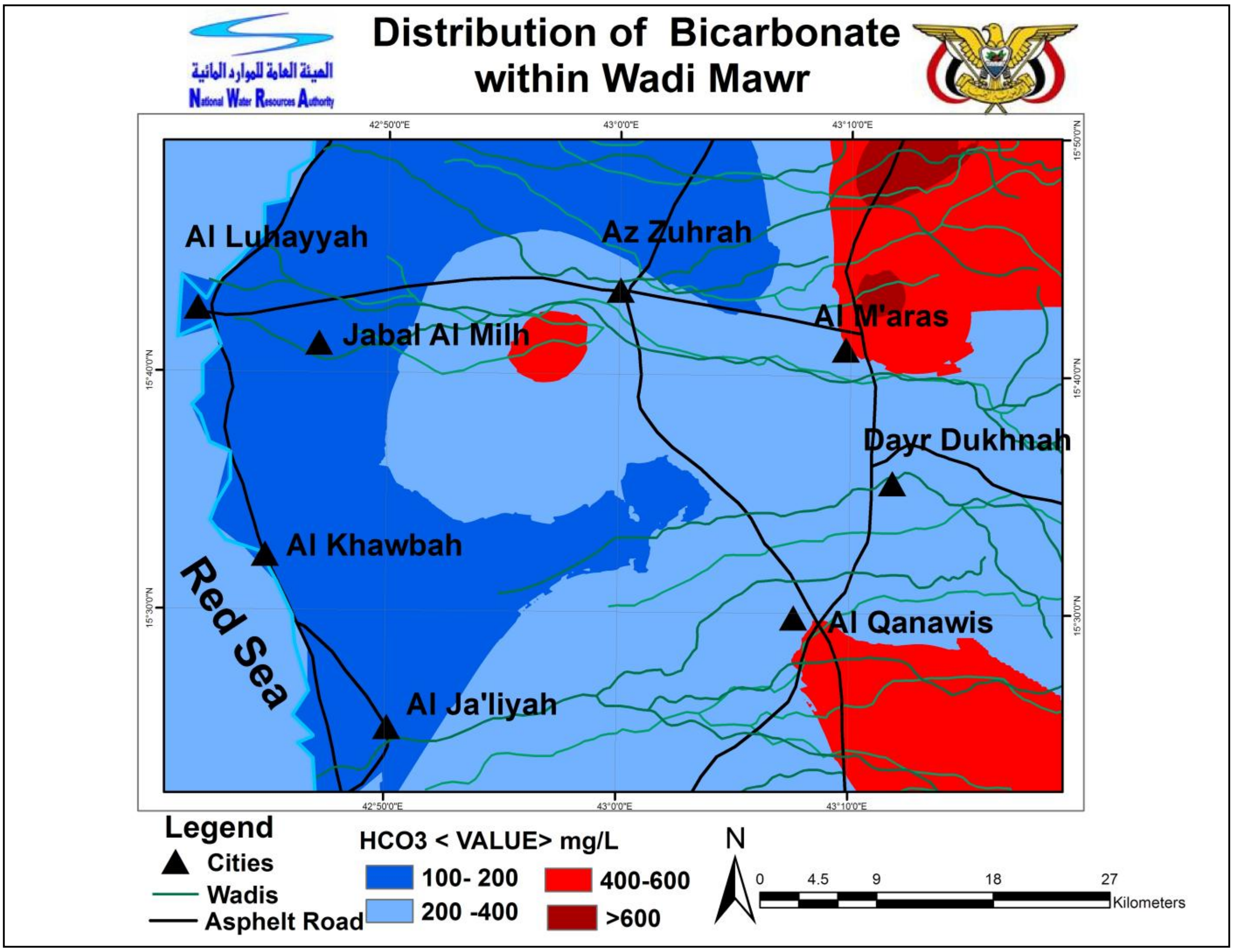

Figure 12: Concentration of Bicarbonate in Wadi Mawr

Sulphate (SO4)

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 Wadi Mawr, Sulphate content ranges between 50 mg/l –2785mg/l with Average 484 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 regions and gradually less as we head east.

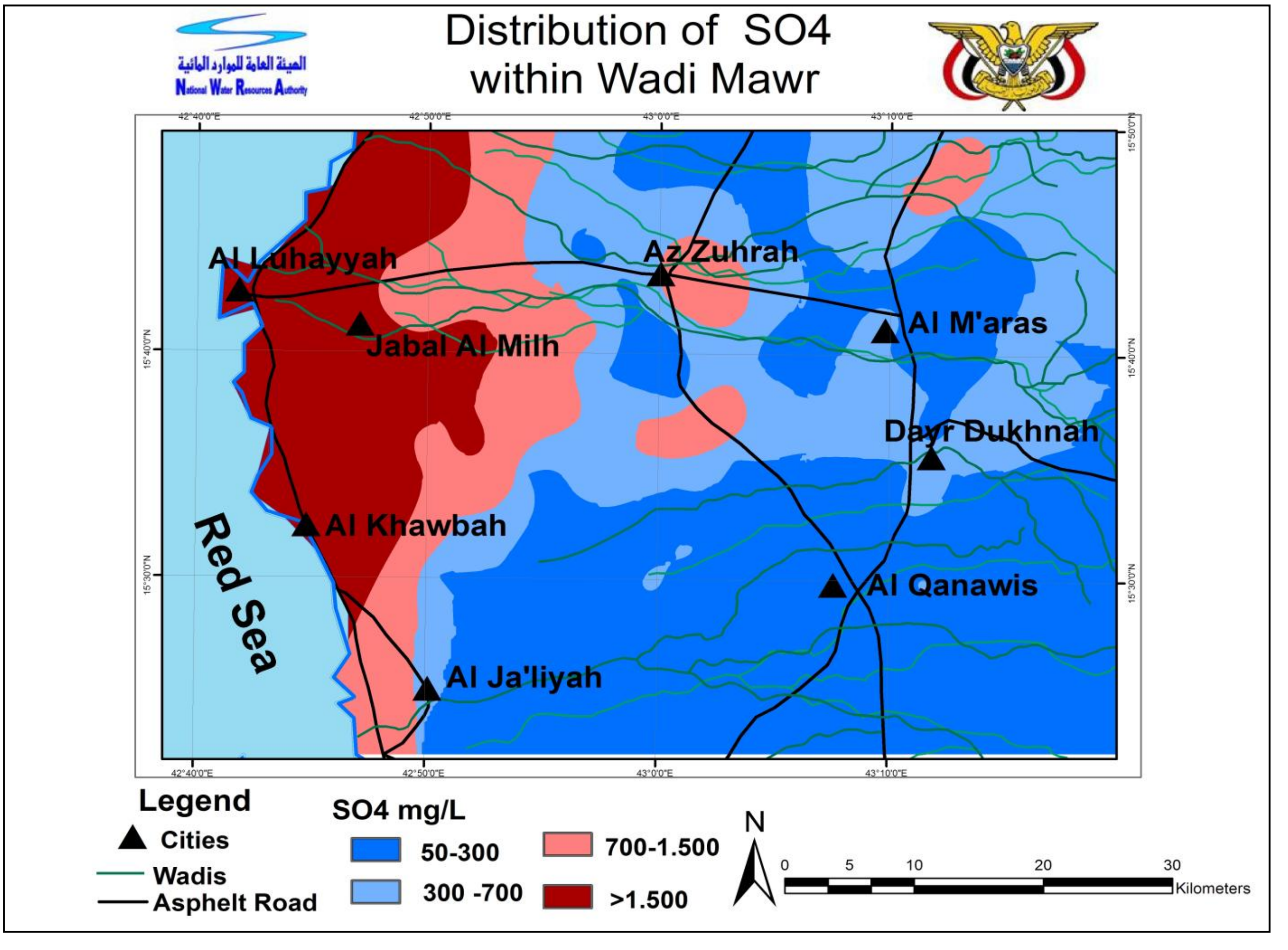

Figure 13: Concentration of Sulfate in Wadi Mawr

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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 Mawr ranges between 66 mg/l – 2688 mg/l with average 646 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).

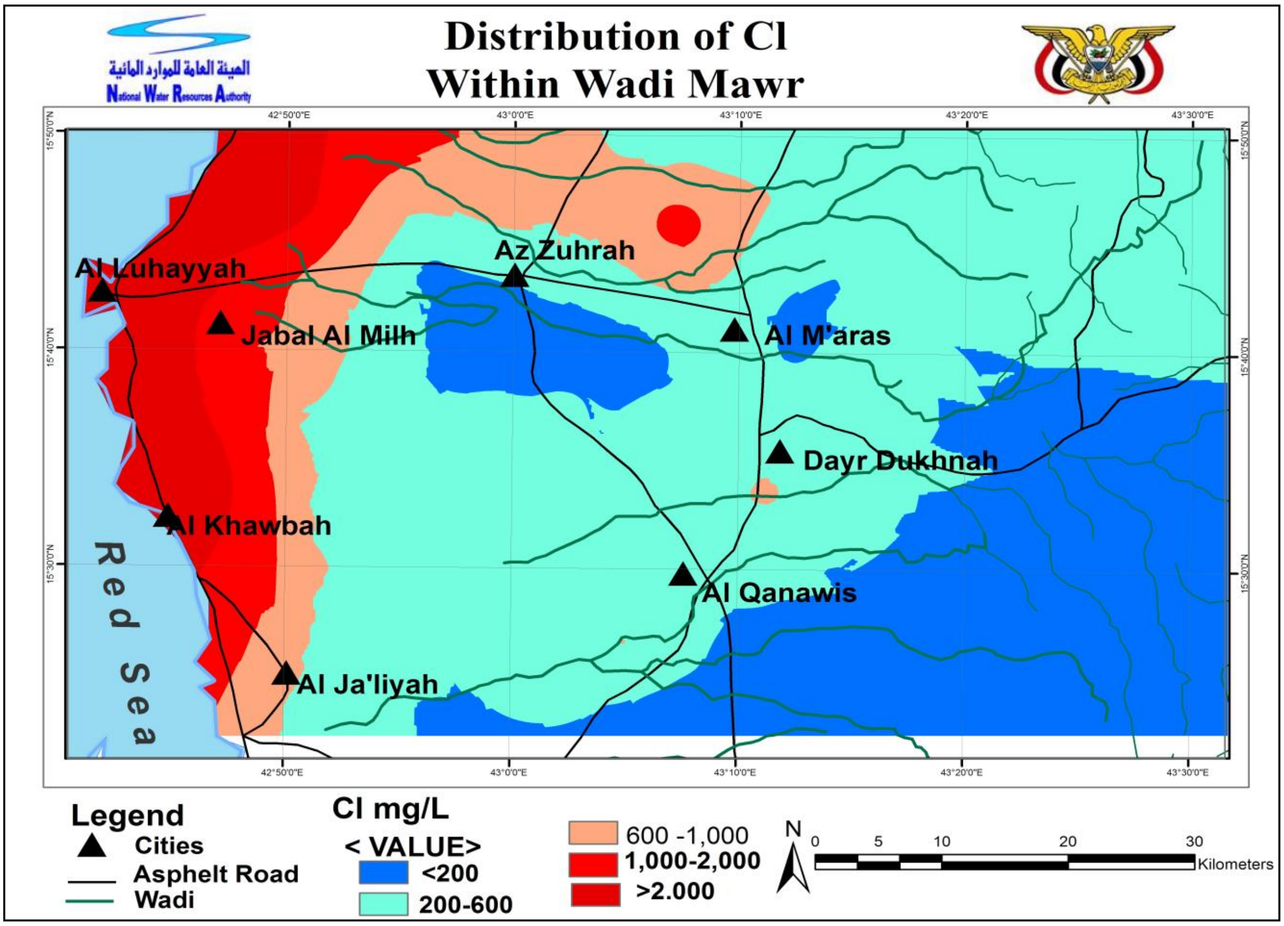

Figure 14: Concentration of Chloride in Wadi Mawr

Nitrate NO3

In the 107 analyzed samples from Wadi Mawr, nitrate ranges from 59.8 mg/l - 880 mg/l with an average of 101 mg/l. fifty five 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 .

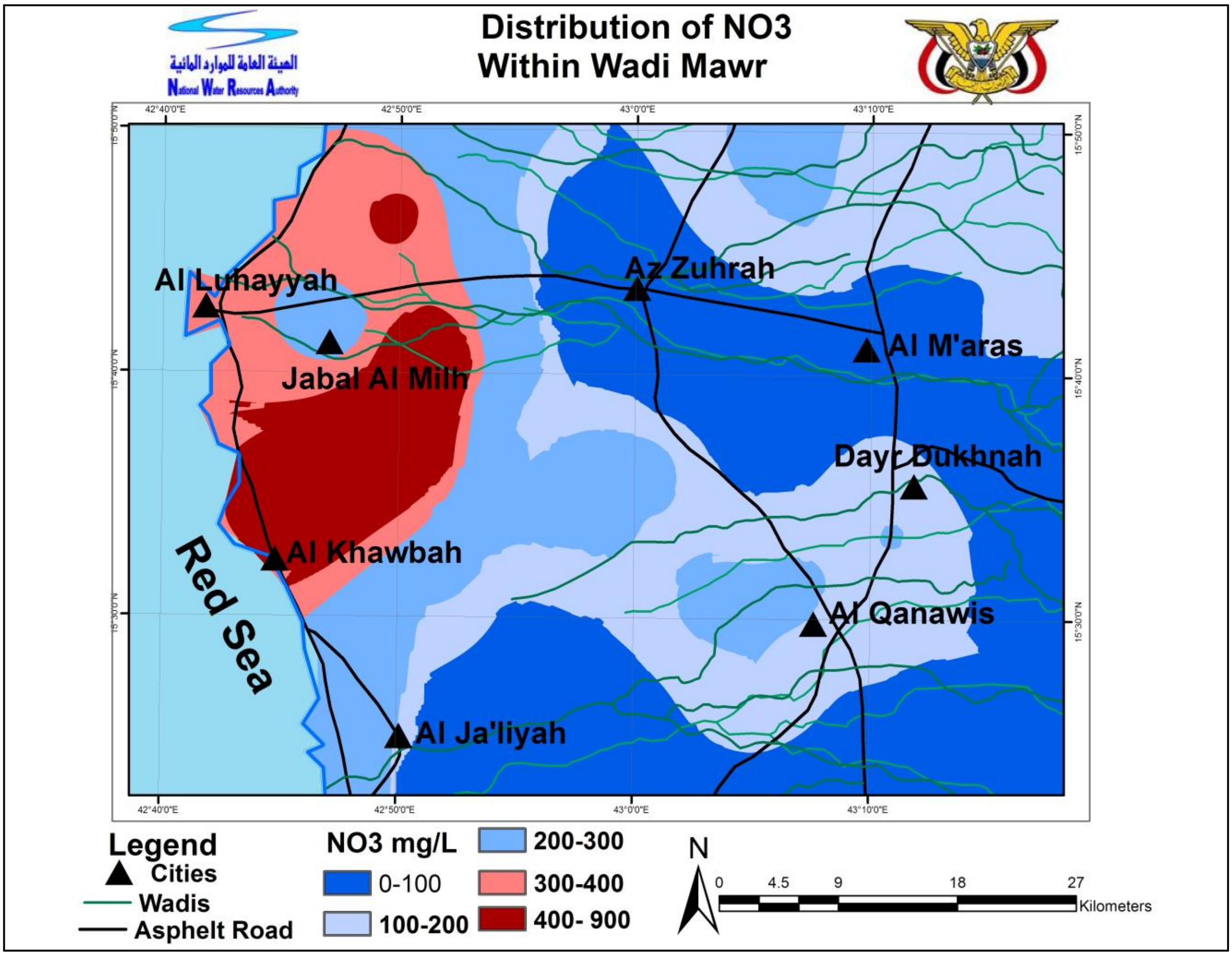

Figure 15: Concentration of Nitrate in Wadi Mawr

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 0.25 – 6.69 mg/l in Wadi Mawr.

There are10 samples which exceed the Yemeni standard for drinking water (Yemen standard ranges between 0.5-1.5 mg/l)in Wadi Mawr .

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 distribution the fluoride concentration in the area.

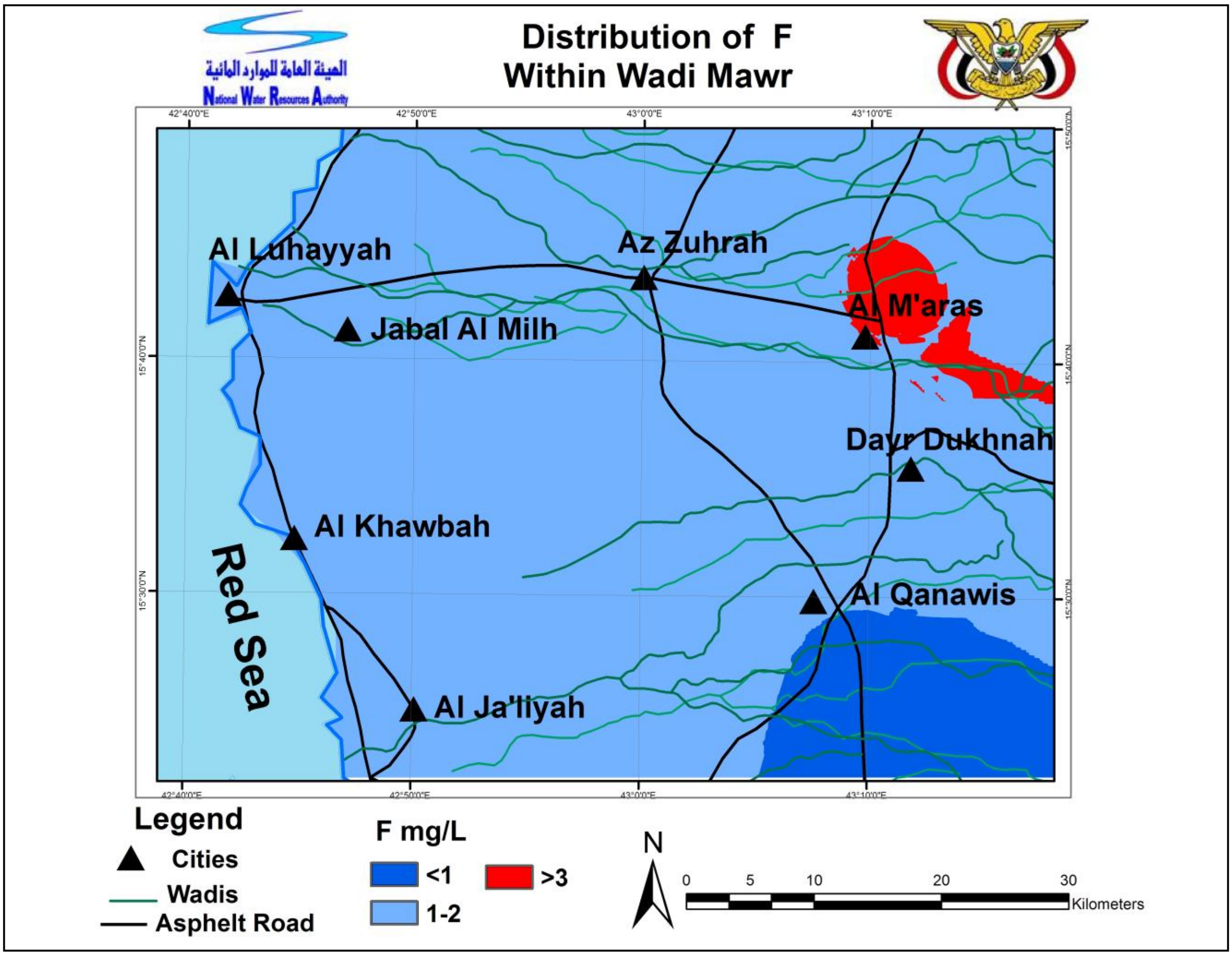

Figure 16: Concentration map of Fluoride in Wadi Mawr

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 in Wadi Mawr. (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	7.2	8.4	6.5		Mg	114	374	14	12
T	34	41.3	29		Cl	646	2688	66	28
EC	3216	11650	907	32	HCO3	287	1041	101	0.7
TDS	2235	9728	653	32	SO4	484	2785	50	20
TH	854	2560	70	42	NO3	101	880	59.8	38
Na	414	2325	89	26	Fe	0.0917	1.62	0	-
K	7.24	38.5	1.8	-	F	1.005	6.699	0.25	21
Ca	154	510	5	13					

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

3- 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.

Iin 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).

4- Chemical water type in Wadi Mawr

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 (16 A, B) and discussed below.

4-1 Types of the chemical water

4-1-1Chemical Classification of Water Wadi Mawr

Requires classification of water and Wadi Mawr 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 is the lowest Conceive is in 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 53 samples (50%) 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 3 samples (3%) 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 CO_2 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 51 sample found (47%) 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.

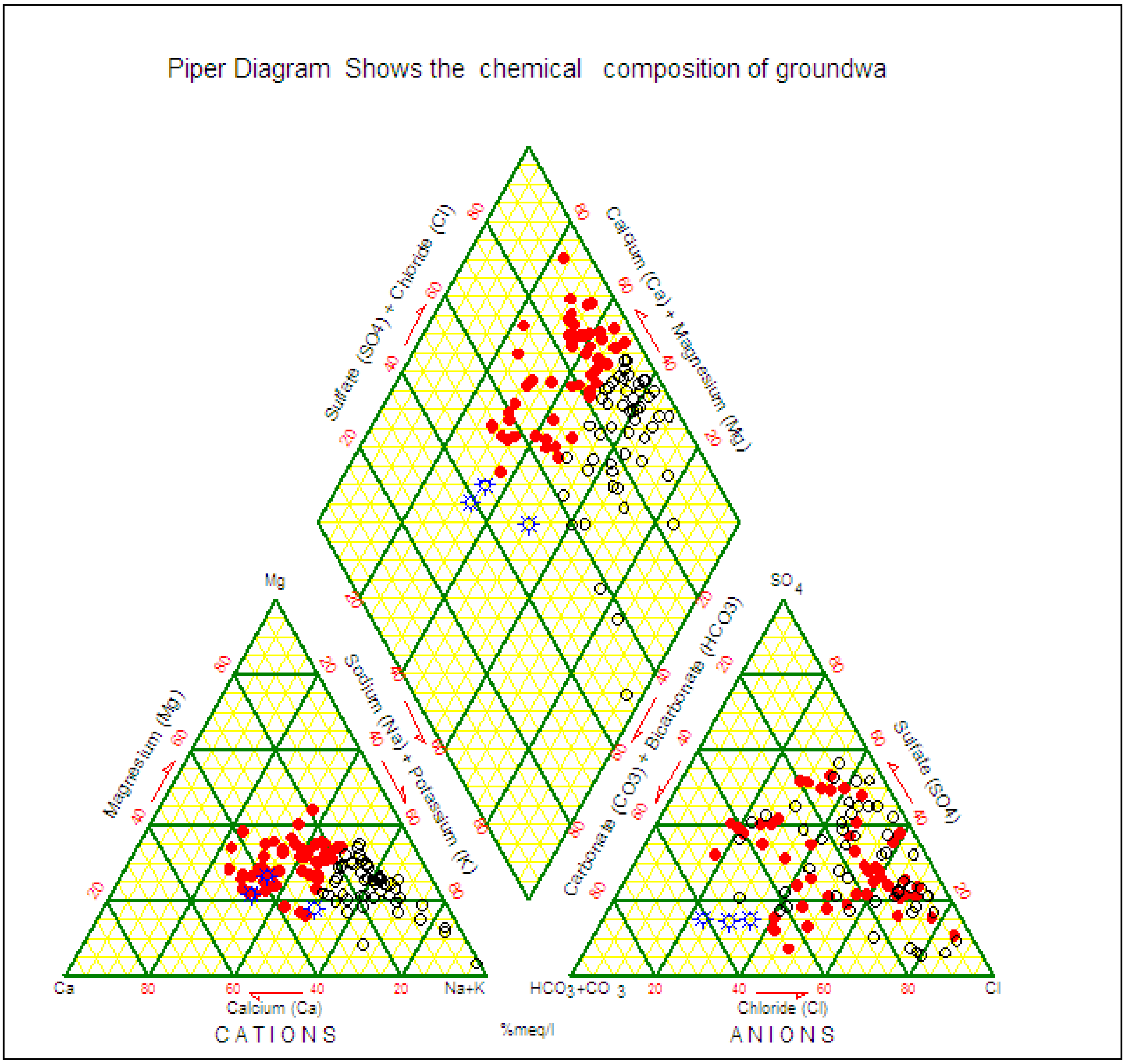

Figure 17: The Piper Digram of Wadi Mawr

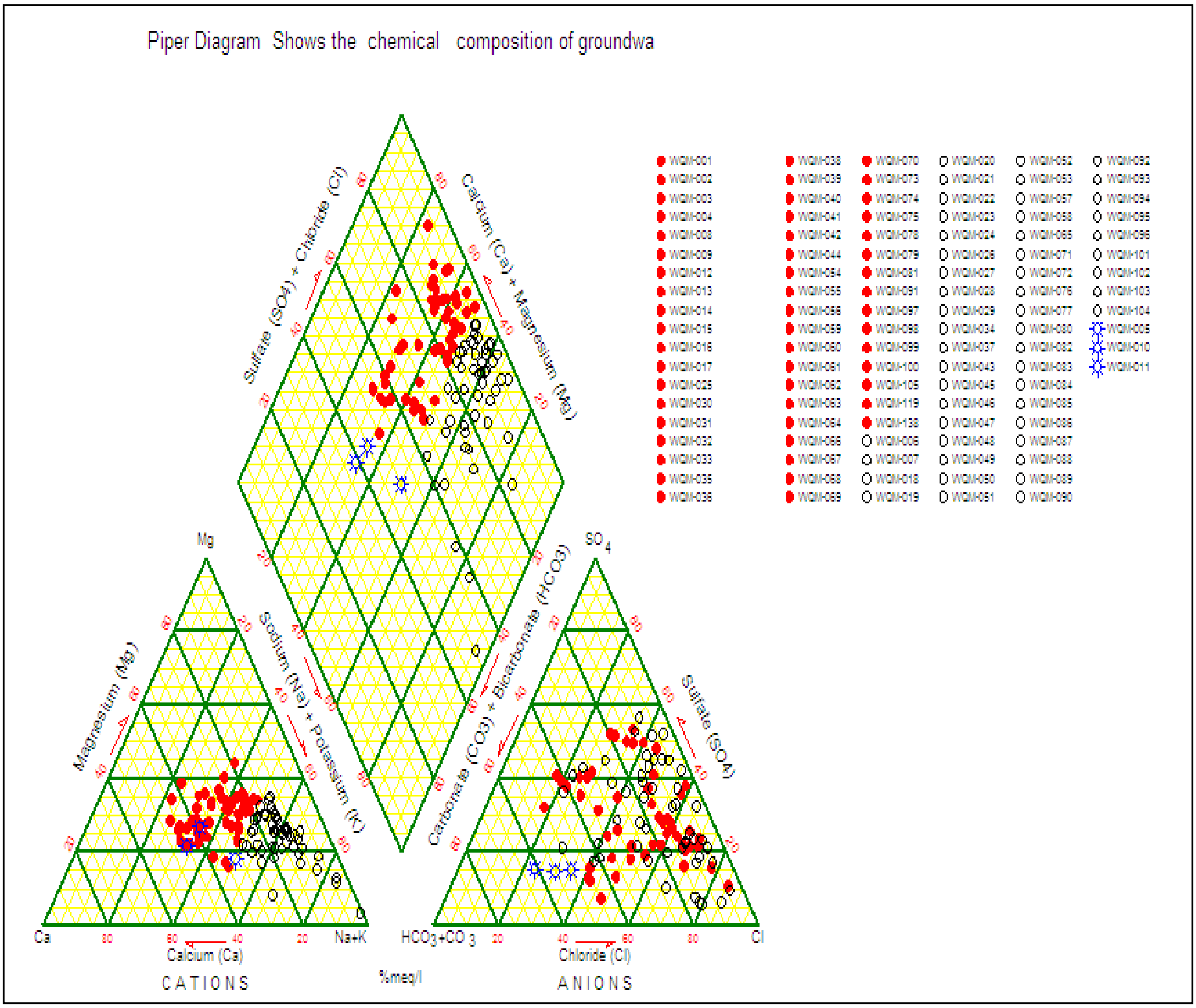

Figure 18: The Piper Digram of Wadi Mawr

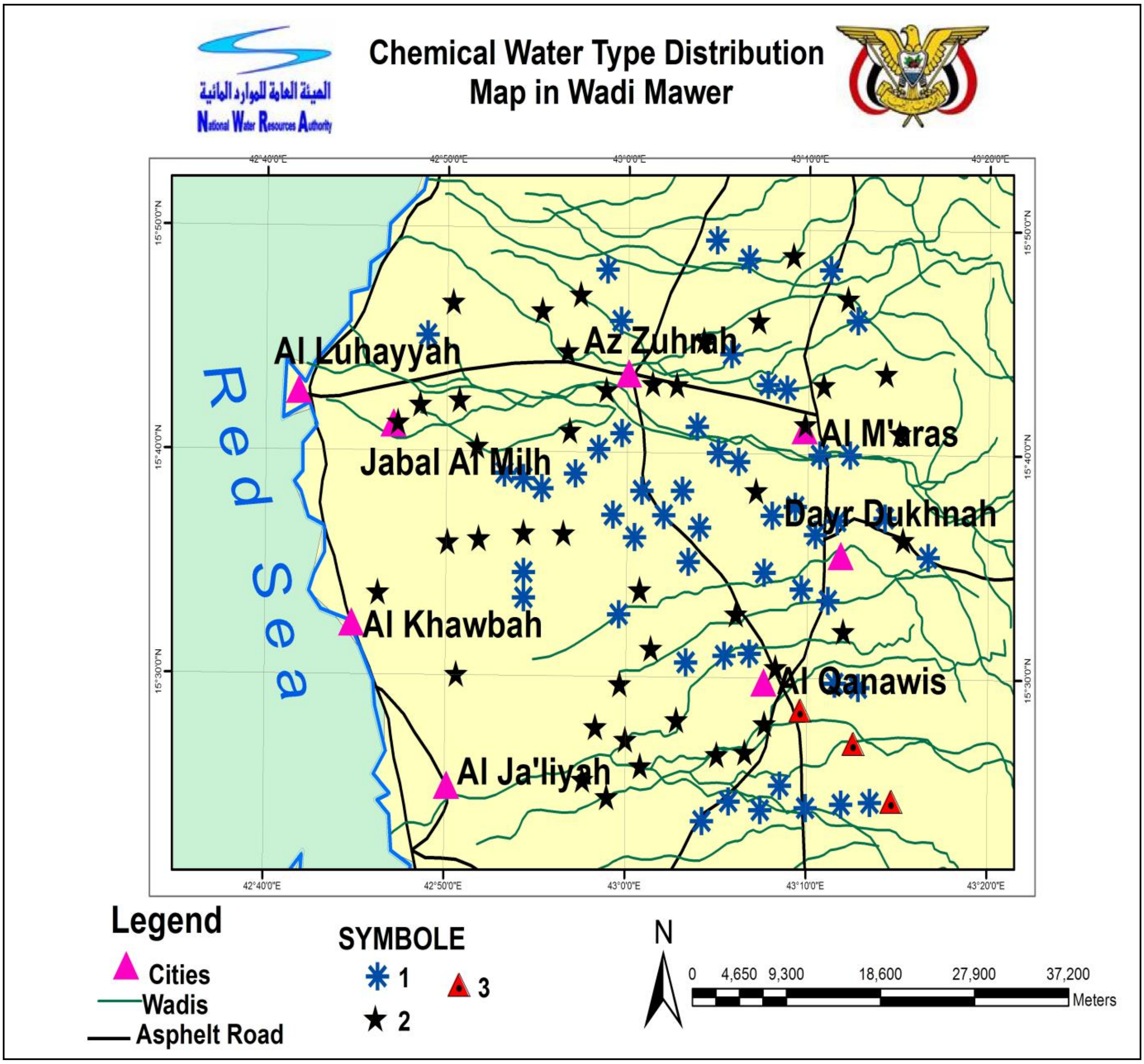

Figure 19: Chemical Water Type Distribution Map in Wadi Mawer

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 19.

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

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

Where

H is the depth of fresh water below sea level

h is the depth of fresh water above sea level

ρ_s is the density of salt water

ρ_f is the density of fresh water

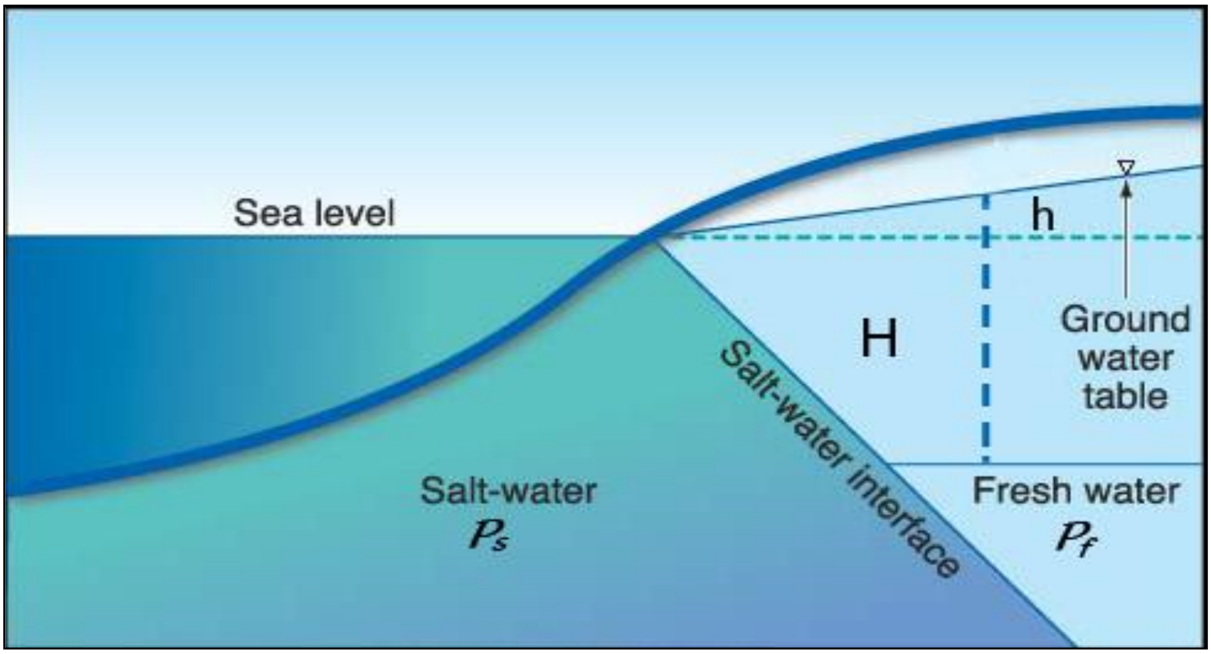

Figure20: Salt water Intrusion phenomena

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 Mawr , especially in Al Khawbah to Jabal Al Milh and Al Luhayyah 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 Mawr

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 24 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 75% of the samples had levels between Optimal Limits and Maximum Permissible Limit.

With respect to Nitrate element, only 58 % of samples (14 sample) were found over Maximum Permissible Limit (MPL). These samples were concentrated in the west / north of the study area, and for Chloride, about 38% of samples (9 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 4 % (1 sample) were found over Maximum Permissible Limit (MPL).

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

Element	Optimal Limits (mg/l)	Samples within (OL)	Maximum Permissible Limit(mg/l)	Samples within (MPL)	Samples over the (MPL)
TDS	650	00	1500	15	9
Calcium	75	2	200	18	4
Magnesium	30	1	150	20	3
Sodium	200	6	400	11	7
Potassium	8	16	12	5	3
Bicarbonate	150	1	500	23	00
Chloride	200	3	600	12	9
Sulfate	200	7	400	12	5
Nitrate	10	3	50	7	14
Iron	0.3	19	1	4	1
Flouride	0.5	1	1.5	22	1
Total Hardness	100	0	500	6	18

5-3 Water supply in wadi Mawr

According to the field information of sampled wells, only 29 wells are in use for water supply.

Only 15 well are borehole well, 8 wells are dug and 12 wells are dug/bore. Results of drinking water quality classifications for samples collected from these wells are given in table (5).

It should noted that 55% of the supply and domestic wells (24 wells) are classified as unsuitable for drinking water on account of one element or more exceeded the Yemeni standard. More than 78 % (23 samples) of samples were had levels higher than the MPL with respect to Nitrate and more than 28% of samples (8 sample) had levels higher than the MPL with respect to fluoride.

Only two sample.

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

Element	Optimal Limits (mg/l)	Samples within (OL)	Maximum Permissible Limit(mg/l)	Samples within (MPL)	Samples over the (MPL)
TDS	650	00	1500	10	19
Calcium	75	10	200	16	3
Magnesium	30	1	150	26	2
Sodium	200	9	400	16	4
Potassium	8	24	12	5	0
Bicarbonate	150	0	500	29	00
Chloride	200	6	600	16	7
Sulfate	200	11	400	12	6
Nitrate	10	2	50	19	8
Iron	0.3	27	1	2	0
Flouride	0.5	6	1.5	21	2
Total Hardness	100	0	500	15	14

Table 6: The water samples exceed the Yemeni standard of Drinking Water in Wadi Mawr

Well No	Site	well type	Location		N0. of exceed elements	Exceed Element Type
			UTM East	UTM North		
WQM-1	Village Dyer Al Rahmah	Dug/Bore	295583	1704360	2	TH, NO3
WQM-4	Village Al Qrety	Bore	303199	1703803	1	TH
WQM- 5	Village Al Kalifh	Bore	302609	1711875	1	NO3
WQM- 7	Village Al Abed	Dug/Bor	297188	1708462	4	TDS, TH ,NO3,EC
WQM-8	Al Hapath	Dug/Bor	308409	1713708	2	TH,NO3
WQM-9	Project Water AlMwzanh	Bore	306095	1714071	6	TDS, TH ,NO3,EC,Cl,Ca
WQM-14	Village Dyer Ksharp	Bore	297667	1716529	6	TDS, TH ,NO3,EC,Cl,Ca
WQM-15	Village Kazaph	Bore	295171	1716366	3	TDS, TH ,NO3
WQM-16	Village Dyer Al Mafcal	Dug/Bor	291375	1715819	4	TDS, TH, F,NO_3
WQM-18	Village Dyer Al Maktaf	Bore	287916	1717029	6	TDS, TH ,NO3,EC,Cl,Na
WQM-19	Dyer Al Sahely	Dug/Bor	294412	1708277	7	TDS, TH ,NO3,EC,Cl,Na,Mg
WQM-20	Al Hamaua	Dug/Bor	286852	1707357	4	TDS ,EC,Cl,Na,
WQM-21	Village Dyer Al Gabaly	Bore	285369	1709522	4	TDS ,EC,Cl,Na
WQM-26	Project Village Atewal	Dug/Bor	290432	1711143	5	TDS, TH,EC,Cl,Na,
WQM-29	Dyer AlQnaes	Bore	300249	1715445	6	TDS, TH ,NO3,EC,Cl,Na,
WQM-31	Dyer Al Heja	Bore	306374	1727441	2	NO_3,TH
WQM-32	AlKhacm	Dug/Bor	304206	1726303	6	TDS, TH ,NO3,EC,Ca, SO4

WQM-36	Village Dyer Dkhna	Bore	299144	1723184	5	Ca,Cl,TDS, TH,EC,
WQM-37	Bani Hefan	Dug/Bor	312896	1725900	7	TDS, TH,EC,Cl,Na,F,K
WQM-42	Project Village Wahan	Dug/Bor	291643	1724102	2	NO_3,TH
WQM-46	Village Al Abaleah	Bore	277024	1722980	1	,NO_3
WQM-54	Dyer Uones	Bore	289212	1727943	8	TDS, TH ,NO3,EC,Ca, SO4,Mg,Cl
WQM-55	Dyer Al Akras	Boer	284192	1727976	5	TDS, TH ,NO3,EC, SO4
WQM-57	Village Dyer Al Wotifah	Bore	279272	1726539	6	TDS, TH ,NO3,EC, SO4,Na
WQM-58	Dyer Mena	Bore	275345	1726603	9	,Mg,SO4,TDS, TH,EC,Cl,Na,NO3,K
WQM-59	Village Dyer Al Hadad	Bore	275345	1723273	5	TDS, TDS, TH,Fe, Ca
WQM-64	Al Sead Abo Al Kaet	Dug	299939	1727885	7	TDS, TH,EC,Ca, SO4,Mg,Cl
WQM-66	Dyer Dwman	Dug	292756	1726918	3	TDS, TH, SO4
WQM-67	Project Behelh Esmail	Boer	291069	1729941	4	TDS, TH,EC, SO4
WQM-68	Village Al Merdaf	Dug	296632	1732323	1	TH
WQM-70	Village Al Eadah	Dug/Bore	292532	1735218	2	TH, SO4
WQM-75	City Mawr	Boer	282793	1733386	1	TH
WQM-79	Dyer Al Kamos	Boer	299565	1738664	7	TDS, TH,EC,Na, NO3,Mg,Cl
WQM-81	Kadef Abdo Hady	Boer	295961	1741195	5	TDS, TH,EC, NO3, ,Cl
WQM-82	Dyer Kadry	Boer	293239	1742415	6	TH,EC,Cl ,NO3,K TDS
WQM-83	Al Zahrah	Boer	283566	1738316	1	F

WQM-96	Al Zabery	Dug	302114	1749358	5	TDS, TH,EC, SO4, NO3,
WQM-97	Project Al Karbah	Bore	297720	1748989	4	TDS, TH,EC, NO3,
WQM-102	Village Al Kabwreah	Dug/Bore	277268	1744890	5	,TDS, TH,EC, SO4 Na,

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 in Wadi Mawr

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	0	Sensitive plants may show stress; moderate leaching prevents salt accumulation in soil.
C3	750 - 2250	36	Salinity will adversely affect most plants; requires selection of salt-tolerant plants, careful irrigation, good drainage, and leaching.
C4	> 2250	70	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 C3 water type (36 sample) with EC values between 750- 2250 (µS/cm), while70 samples were C4 with EC > 2250 µS/cm). 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.

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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 Mawr 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: $Na^{+1} > Ca^{+2} > Mg^{+2} \geq K^{+1}$ and $Cl^{-1} > HCO_3^{-1} > SO_4^{-2} > NO_3^{-1}$.
- 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 are unfit for irrigation purposes.

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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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 1	D 175	Village Dyer Al Rahmah	Dug/Bore	295583	1704360	80	Domestic
WQM 2	D 2	Village Al Daoreh	Bore	2983712	1703646	100	Supply
WQM 3	D 16	Dyer Mohamad (AlQnaes)	Bore	300662	1705663	140	Irrigation
WQM 4	D 41	Project Village Al Qrety	Bore	303199	1703803	100	Supply
WQM 5	D 103	Village Al Kalifah	Bore	302609	1711875	100	Domestic
WQM 6	E185	Village AlKalel	Bore	299131	1710819	120	Supply
WQM 7	E 102	Village Al Abed	Dug/Bore	297188	1708462	120	Supply
WQM 8	D 199	Al Hapath	Dug/Bore	308409	1713708	40	Domestic
WQM 9	D 217	Project Water AlMwzanh	Bore	306095	1714071	120	Domestic
WQM 10	D 131	Village Dojan	Bore	307835	1709126	115	Supply
WQM 11	D 133	Village Al metbar	Bore	311581	1704348	120	Supply
WQM 12	D 76	Alhograh	Dug	309539	1704248	40	Irrigation
WQM 13	D 77	Al Atawea	Bore	306706	1704102	80	Irrigation
WQM 14	E 176	Village Dyer Ksharp	Bore	297667	1716529	85	Domestic
WQM 15	E 159	Village Kazaph	Bore	295171	1716366	80	Supply
WQM 16	E 190	Village Dyer Al Mafcal	Dug/Bore	291375	1715819	110	Supply
WQM 18	E 197	Village Dyer Al Maktaf	Bore	287916	1717029	80	Supply
WQM 19	E 109	Dyer Al Sahely	Dug/Bore	294412	1708277	95	Domestic
WQM 20	E 23	AlHamaua	Dug/Bore	286852	1707357	70	Domestic
WQM 21	E 76	Village Dyer Al Gabaly	Bore	285369	1709522	80	Supply
WQM 22	E 84	Village Al Zeah	Bore	282403	1710575	120	Domestic
WQM 23	E 124	Village Al Mofedfeah	Bore	281140	1706228	120	Supply
WQM 24	E 135	Village Dyer Mwmen	Bore	283527	1704801	99	Supply
WQM 25	E 4	Village Dyer Ata	Dug/Bore	292947	1702734	72	Supply
WQM 26	E 53	Project Village Atewal	Dug/Bore	290432	1711143	83	Supply
WQM 27	E 429	AlHagey	Bore	284825	1714115	50	Irrigation
WQM 28	E 372	Read Aob Resh	Bore	296345	1719838	88	Irrigation
WQM 29	E 260	Dyer AlQnaes	Bore	300249	1715445	120	Domestic
WQM 30	D 266	Azan AlQnaes	Bore	305454	1720876	100	Irrigation
WQM 31	D 310	Dyer Al Heja	Bore	306374	1727441	70	Domestic
WQM 32	A 2	AlKhacm	Dug/Bore	304206	1726303	49	Domestic
WQM 33	A 7	AlKhacm	Bore	302228	1728616	60	Irrigation

WQM 34	D 245	Village AlHapath	Bore	306950	1718409	75	Domestic
WQM 35	E 315	AlQnaes Dyer Seaf	Bore	302809	1721828	120	Irrigation
WQM 36	A 497	Village Dyer Dkhna	Bore	299144	1723184	61	Supply
WQM 37	D 350	Bani Hefan	Dug/Bore	312896	1725900	55	Domestic
WQM 38	D365	Bani Marzwk	Dug	315374	1724394	36	Irrigation
WQM 39	D 326	Al Heky Al Thwr	Dug	311083	1727642	37	Irrigation
WQM 40	D 374	Al Hagor	Dug/Bore	304665	1732857	40	Irrigation
WQM 41	D 407	Naklh	Dug	307658	1732857	7	Irrigation
WQM 42	A 529	Project Village Wahan	Dug/Bore	291643	1724102	50	Supply
WQM 43	E 440	Dyer Al Balced	Dug/Bore	286838	1721848	105	Domestic
WQM 44	E 457	Dyer Mardm	Bore	284765	1719782	100	*Irrigation*
WQM 45	C 3	Al Kas	Dug/Bore	280632	1722949	100	Irrigation
WQM 46	C 514	Village Al Abaleah	Bore	277024	1722980	130	Supply
WQM 47	C 534	Al Zoleah	Bore	273530	1723152	85	Irrigation
WQM 48	E 602	Dyer Mosa	Dug/Bore	279552	1717653	60	Irrigation
WQM 49	E 434	Dyer Mosa Mosa	Bore	277472	1716423	147	Supply
WQM 50	E 632	Dyer Rajeh	Bore	275100	1715787	80	Irrigation
WQM 51	E 643A	Dyer Rajeh	Bore	272892	1716231	70	Irrigation
WQM 52	F 35	Dyer Al Kadary	Dug/Bore	270973	1718334	70	Irrigation
WQM 53	E 676A	Dyer Rajeh	Bore	268663	1714953	75	
WQM 54	A 565	Dyer Uone	Bore	289212	1727943	58	Supply
WQM 55	A 672	Dyer Al Akras	Bore	284192	1727976	200	Supply
WQM 56	A 627	Dyer Al Bask	Bore	286319	1726143	60	Irrigation
WQM 57	C 500	Village Dyer Al Wotifah	Bore	279272	1726539	120	Supply
WQM 58	C476	Dyer Mena	Bore	275345	1726603	75	Domestic
WQM 59	A 500	Village Dyer Al Hadad	Bore	275345	1723273	100	Domestic
WQM 60	E 481A	Al Maksabh	Bore	275345	1721168	90	Irrigation
WQM 61	C 480	Al Baky	Dug/Bore	275345	1730993	76	Irrigation
WQM 62	C 456 A	Al Osha	Bore	277164	1730157	60	Irrigation
WQM 63	C 481	Al Bakayh	Bore	280483	1731384	80	Irrigation
WQM 64	A 16	Al Sead Abo Al Kaet	Dug	299939	1727885	30	Supply
WQM 65	A 182	Kerf Al Ktape	Dug	298345	1730003	120	Domestic
WQM 66	A 437	Dyer Dwman	Dug	292756	1726918	52	Supply
WQM 67	A 353	Project Behelh Esmail	Bore	291069	1729941	85	Domestic
WQM 68	A 256	Village Al Merdaf	Dug	296632	1732323	7	Domestic
WQM 69	B 62	Village Al Merdaf	Dug	294623	1733055	12	Irrigation
WQM 70	B 467	Village Al Eadah	Dug/Bore	292532	1735218	36	Supply
WQM 71	B 579	Al Motared	Bore	288160	1738830	90	Irrigation
WQM 72	B 481	Dyer Rajeh	Bore	290545	1738739	90	Irrigation

WQM 73	A 415	VillageAl Masany	Bore	287054	1729941	46	Supply
WQM 74	B 702	Al Maslabeah	Bore	285101	1734689	65	Irrigation
WQM 75	B 653	City Mawr	Bore	282793	1733386	100	Supply
WQM 76	C 375	Al Zabeah	Bore	279936	1734991	65	Irrigation
WQM 77	C 335	Village Kazmh	Bore	279752	1741520	150	Supply
WQM 78	D 673	Dyer Al Kamos	Bore	301429	1738286	21	Irrigation
WQM 79	D 688	Dyer Al Kamos	Bore	299565	1738664	80	Domestic
WQM 80	D 742	Dyer Al Odaby	Dug/Bore	298656	1743978	65	Irrigation
WQM 81	A 721	Kadef Abdo Hady	Bore	295961	1741195	81	Supply
WQM 82	A 735	Dyer Kadry	Bore	293239	1742415	36	Domestic
WQM 83	B 590	Al Zahrah	Bore	283566	1738316	100	Supply
WQM 84	C 590	Al Wrmah	Bore	260929	1721738	12	Irrigation
WQM 85	C 618	Village Al Deraseh	Bore	267834	1725872	90	Irrigation
WQM 86	C 554	Yasen Dyer	Bore	270900	1726124	70	Irrigation
WQM 87	C 144	Al Oquleah	Bore	269055	1737577	150	Irrigation
WQM 88	C 72	Al Karamh	Bore	265162	1737201	70	Irrigation
WQM 89	C 47	Al Sawager	Dug	262965	1735734	24	Animal
WQM 90	C 318	Al Karabesh	Bore	270763	1733755	75	Irrigation
WQM 91	C 326	Al Wrmah	Bore	273475	1731453	90	Irrigation
WQM 92	D 649	Al Saef	Dug	303229	1735424	20	Irrigation
WQM 93	D 563	Mehsam Al Mohana	Dug	305060	1738666	11	Irrigation
WQM 94	D 430	Kedenah	Dug	312611	1734699	25	Irrigation
WQM 95	D 632	Back Al Masged	Dug	311234	1739572	15	Irrigation
WQM 96	D 817	Al Zabery	Dug	302114	1749358	32	Domestic
WQM 97	D 768	Project Al Karbah	Bore	297720	1748989	100	Domestic
WQM 98	D 755	Village Al Abadelah	Bore	294556	1750561	110	Irrigation
WQM 99	F217	Seab Al Aswal	Bore	283728	1748181	90	Irrigation
WQM 100	F 241	Al Womrayh	Bore	285055	1743949	75	Irrigation
WQM 101	F 216	Al Daraweseh	Bore	281068	1746200	50	Irrigation
WQM 102	F 163	Village Al Kabwreah	Dug/Bore	277268	1744890	80	Domestic
WQM 103	B 825	Al Adeleh	Bore	307476	1745776	57	Irrigation
WQM 104	B 803	Al Luheah	Bore	268478	1745606	100	Irrigation
WQM 105	C 132	Al Nasedeh	Bore	265922	1742841	42	Irrigation
WQM 119	D 856	Al Aragh	Dug	308469	1743891	15	Irrigation
WQM 138	D 931	Jabal Al Swme Al Kdenah	Dug	305792	1748105	36	Irrigation

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-1	1548	6.88	35	1006.2	566	280	276	130.0	0.66	107	72	119.6	2.3	59.84	0.26
WQM-2	1371	7.18	34	891.2	486	307	236	85.0	0.46	120	45	98.8	2.1	18.48	0.02
WQM-3	2380	6.75	35	1547.0	988	377	483	225.0	0.37	220	106	129	2.9	43.56	0.03
WQM-4	1421	7.01	34	923.7	506	391	242	50.0	0.44	120	50	107.9	2.1	19.8	0
WQM-5	1302	6.89	36	846.3	432	381	120	80.0	0.43	102	43	104.4	1.9	90.2	0.06
WQM-6	1799	7.04	36	1169.4	384	443	270	160.0	0.39	71	50	269.7	2.5	34.32	0.01
WQM-7	2640	7.01	35	1716.0	506	348	574	120.0	0.51	89	69	392	3.4	111.3	0.06
WQM-8	2240	6.98	32.4	1456.0	621	385	395	230.0	0.84	171	47	273	2.4	98.12	0.04
WQM-9	3710	6.85	35	2411.5	1296	273	855	391.0	0.72	349	103	282	2.8	104.7	0.04
WQM-10	1110	6.94	34	721.5	393	411	92	81.3	0.41	106	31	89	1.9	23.32	0
WQM-11	1199	7.36	35.7	779.4	310	367	148	87.5	1.06	79	27	139.5	4.6	3.52	0.08
WQM-12	1553	6.91	33.8	1009.5	544	420	224	118.8	0.25	145	44	127.5	1.8	8.36	0.04
WQM-13	1460	6.75	33.1	949.0	556	423	225	87.5	0.42	142	49	102.0	2.2	24.2	0.02
WQM-14	3390	6.77	35.4	2203.5	1094	280	762	240.0	0.73	218	134	270.0	8.8	218.2	0.07
WQM-15	2310	7.28	35	1501.5	690	269	410	215.0	0.88	142	81	227.5	6.1	75.68	0.2
WQM-16	2330	7.22	33	1514.5	636	244	438	220.0	1.55	102	93	261.9	6.2	238.5	0.03
WQM-18	3680	7.61	35.8	2392.0	741	229	792	370.0	0.86	108	114	484.5	8.4	105.6	0
WQM-19	5190	7.3	35	3373.5	980	245	1456	145.0	0.98	142	152	705.0	5.1	153.1	0.05
WQM-20	3230	8	35.6	2099.5	245	291	818	110.0	0.6	25	45	610	3.5	30.36	0.19
WQM-21	3910	7.64	35.7	2541.5	445	244	960	304.2	0.89	63	70	674.5	3.6	32.56	0.43

WQM-22	1576	7.69	37.9	1024.4	136	427	241	140.0	0.91	11	26	315	3.7	0.44	0.03
WQM-23	1799	7.58	38.6	1169.4	337	272	358	150.0	0.82	40	57	282.9	4.4	31.68	0.02
WQM-24	1834	7.74	34.7	1192.1	406	299	340	190.0	0.94	51	68	241.8	3.8	32.56	0
WQM 25	1300	7.38	34	845.0	369	275	202	110.0	0.9	55	57	132.3	3.2	32.12	0.09
WQM-26	3080	7.56	37	2002.0	569	256	821	80.0	1.11	76	94	423.3	5.7	69.96	0
WQM-27	4450	7.39	35.3	2892.5	1016	233	1078	375.0	1.22	115	177	504.9	6.6	77.88	0.11
WQM-28	2210	7.03	31.5	1436.5	517	271	382	260.0	0.72	106	61	285.2	7.8	113.5	0.02
WQM-29	5270	7.42	35.3	3425.5	836	454	1374	150.0	0.91	125	127	833	7	95.92	0.36
WQM-30	6510	6.51	33.8	4231.5	2560	260	1749	480.0	0.62	510	311	348.5	5.4	223	0.01
WQM-31	1854	7.05	33.8	1205.1	633	305	270	325.0	0.76	158	58	165.9	4.4	57.64	0.1
WQM-32	2920	7.02	34.7	1898.0	974	279	558	410.0	0.85	251	84	251.1	7.4	112.2	0.07
WQM-33	5170	6.7	34.2	3360.5	1495	271	1253	660.0	0.77	404	118	510	11	53.68	0.04
WQM-34	1531	7	30	995.2	369	369	222	170.0	0.75	84	39	201.6	2.4	23.32	0.33
WQM-35	1627	6.91	34.5	1057.6	632	268	225	180.0	0.9	157	58	92.4	6.3	73.48	0.04
WQM-36	2700	6.98	34.3	1755.0	864	197	639	265.0	0.81	211	82	238.7	8.8	44.44	0.47
WQM-37	3500	7.24	39	2275.0	565	168	832	390.0	3.42	170	34	497.7	29.5	1.32	0.08
WQM-38	1671	6.91	30.2	1086.2	651	363	176	355.0	1.39	139	73	133.5	2.3	14.52	0.81
WQM-39	3450	6.78	33.3	2242.5	925	309	655	440.0	1.88	250	73	373.1	15.9	26.84	0.02
WQM-40	2500	6.96	32	1625.0	830	245	538	310.0	0.68	204	78	198.4	6.4	28.6	0.03
WQM-41	1418	7.15	29	921.7	531	378	119	280.0	0.65	142	43	103.4	7.4	3.96	0.02
WQM-42	2080	7.12	34.4	1352.0	704	202	361	320.0	0.96	157	76	184.8	6.8	51.04	0.17
WQM-43	1861	7.16	35.4	1209.7	484	262	275	330.0	0.51	90	63	232.5	7.6	34.76	0.07
WQM-44	2450	7.08	35.2	1592.5	713	185	471	280.0	0.76	117	102	269.7	7.2	105.6	0.1
WQM-45	2970	7.13	35.4	1930.5	795	258	414	490.0	0.98	110	126	369	5.7	258.7	0.03
WQM-46	2070	7.41	35.2	1345.5	471	197	306	305.0	0.43	69	72	279	6.5	123.2	0
WQM-47	4870	7.23	33.7	3165.5	992	312	689	1016.6	1.03	124	166	720.9	6.6	149.6	0.04

WQM-48	2720	7.34	37.6	1768.0	655	204	600	260.0	0.82	107	94	310	7.5	71.28	0
WQM-49	1859	7.55	41.3	1208.4	333	197	395	170.0	0.5	51	50	263.5	6.6	32.12	0.09
WQM-50	2890	7.38	38.8	1878.5	507	187	635	290.0	0.82	74	78	448.8	6.7	29.48	0.01
WQM-51	3680	7.43	38.1	2392.0	792	174	765	390.0	0.69	122	118	504.1	7.8	115.7	0.02
WQM-52	3550	7.52	35	2307.5	718	174	640	490.0	0.73	103	112	500.2	7.6	220	0
WQM-53	4480	7.59	39	2912.0	929	148	1174	350.0	0.86	120	153	575.1	7.2	38.72	0.07
WQM-54	4540	7.17	34.7	2951.0	1633	212	742	1083.3	1.07	317	204	397.7	7	70.4	0.19
WQM-55	3470	7.27	36	2255.5	1035	240	552	650.0	0.67	188	137	377.4	8.4	122.3	0.03
WQM-56	6090	6.88	34.4	3958.5	1972	187	1028	850.0	0.97	339	273	494.1	7.2	365.2	0
WQM-57	3670	7.15	36.7	2385.5	851	291	473	600.0	0.72	122	133	435.6	7.7	133.3	0.05
WQM-58	4390	7.22	35.1	2853.5	930	285	606	800.0	0.97	120	153	555.1	13.2	87.12	0
WQM-59	2540	7.04	36	1651.0	882	218	536	365.0	0.61	205	93	193.2	8.7	40.48	1.62
WQM-60	2890	7.21	33.8	1878.5	754	221	393	420.0	0.77	133	102	282.1	7.2	153.1	0.01
WQM-61	3040	7.09	33.2	1976.0	840	335	319	740.0	0.85	141	118	332.1	11.1	53.68	0.02
WQM-62	4450	6.83	34	2892.5	1509	292	637	1083.3	1.03	269	204	441	13.6	87.56	0.01
WQM-63	1801	7.06	33.2	1170.7	592	343	183	370.0	0.66	94	87	193.2	7.9	47.96	0.06
WQM-64	4830	6.68	33.5	3139.5	1644	388	1088	570.0	0.78	383	167	389.5	8.7	46.2	0
WQM-65	1520	7.27	32.3	988.0	407	327	144	340.0	1.13	91	44	182.7	12	7.92	0.55
WQM-66	2410	7.11	32.6	1566.5	769	237	304	600.0	0.99	176	80	197.4	5.6	35.2	0.02
WQM-67	2980	7.14	33.5	1937.0	959	260	401	733.3	1.08	178	125	303.8	8.9	21.12	0
WQM-68	1422	7.02	30.7	924.3	523	392	109	295.0	0.77	121	53	105.6	7.7	11	0.01
WQM-69	1119	7.43	32	727.4	345	254	110	190.0	1.04	65	44	93.5	20	3.96	0
WQM-70	2160	7.2	32	1404.0	650	279	234	580.0	1.46	99	98	227.5	7.2	4.4	0.06
WQM-71	4430	7.16	34.9	2879.5	1139	223	536	1175.0	1.43	164	177	591.7	9	49.72	0.02
WQM-72	3770	7.35	34.5	2450.5	1016	271	481	966.6	0.97	163	148	479.4	8.6	33.44	0.28
WQM-73	1101	7.43	31.4	715.7	382	294	72	225.0	0.86	58	58	92.4	6.8	13.64	0.07

WQM-74	1005	7.21	31.9	653.3	348	315	66	160.0	1.65	42	59	90.2	4.6	13.2	0.02
WQM-75	1659	7.28	34	1078.4	525	362	149	330.0	0.98	78	80	178.5	5.9	38.72	0.01
WQM-76	4060	7.15	34.4	2639.0	741	578	417	833.3	1.48	73	135	660.3	5.8	69.52	0.08
WQM-77	1546	7.51	34.3	1004.9	289	350	124	305.0	0.86	38	47	226.3	5.7	25.08	0.1
WQM-78	3380	7.22	31.5	2197.0	893	203	766	333.3	1.07	124	142	369	3.8	46.2	0.03
WQM-79	4480	7.24	33.1	2912.0	1202	172	1153	316.7	1.08	184	180	479.4	4.9	66	0.47
WQM-80	8960	7.02	37.3	5824.0	1878	216	2688	400.0	0.8	290	280	1197.9	7	141.2	0.04
WQM-81	3630	6.95	36.8	2359.5	1083	167	874	360.0	0.68	192	147	346.8	8.2	82.72	0.08
WQM-82	3300	7.25	38	2145.0	783	101	823	320.0	1.03	176	86	382.5	12.2	50.16	0.06
WQM-83	1674	7.7	33.1	1088.1	202	447	135	305.0	2.64	19	37	279	2.1	11.88	0.02
WQM-84	13270	7.15	35	9728.0	2286	225	2675	2785.7	1.95	298	374	2325	14.6	486.9	0
WQM-85	5140	7.35	35.2	3341.0	1183	204	789	1016.6	0.95	126	211	591.3	6.7	440	0.08
WQM-86	6590	7.19	35.8	4283.5	1560	246	873	1475.0	1.23	187	265	828.1	7.8	545.5	0
WQM-87	3980	7.43	38.2	2587.0	889	193	533	716.6	0.86	110	150	504.9	6.4	308	0
WQM-88	6890	7.37	36	4478.5	1088	166	1746	683.3	1	131	185	999	7.8	220	0.01
WQM-89	9400	7.61	31.8	6110.0	2126	194	1468	2321.4	2	501	213	1375.2	13	121.4	0.08
WQM-90	10120	7.3	35.7	6578.0	1924	269	1551	1892.8	1.95	246	318	1413.4	9.2	880	0
WQM-91	3740	7.16	33	2431.0	1134	264	439	916.6	0.94	196	157	360	9.9	195.4	0
WQM-92	2080	7.51	32.2	1352.0	317	327	263	390.0	1.3	54	44	344.4	3.9	32.56	0
WQM-93	3130	8.4	31.7	2034.5	70	964	329	320.0	6.699	5	14	735	2	2.2	0.09
WQM-94	2770	7.66	33.3	1800.5	577	380	481	370.0	0.85	120	67	423.3	3.1	99.44	0
WQM-95	2060	7.51	31.5	1339.0	434	382	320	295.0	0.76	92	50	262.5	3.8	42.24	0.05
WQM-96	2800	7.7	32.5	1820.0	758	245	491	510.0	1.06	128	107	352.6	3.1	82.28	0.01
WQM-97	2980	7.34	35.6	1937.0	1024	225	592	380.0	0.84	182	139	279	3.2	208.6	0.03
WQM-98	2790	7.42	35.2	1813.5	979	164	629	270.0	0.83	195	120	193.2	3	154.9	0.13
WQM-99	4870	7.41	36.5	3165.5	1329	112	1454	250.0	0.65	275	156	479.4	12.2	16.28	0.06

WQM-100	4210	6.93	37.6	2736.5	1057	159	1021	468.8	0.74	217	125	427.5	9.8	17.6	0.03
WQM-101	4550	7.03	37.8	2957.5	1048	157	1125	500.0	0.86	201	132	499.8	10.5	11.44	0
WQM-102	3040	7.44	37.9	1976.0	597	176	564	430.0	0.72	113	77	401.8	9.2	45.32	0.01
WQM-103	6860	7.08	37.3	4459.0	1446	252	1332	1200.0	1.24	213	222	939.3	10	183.9	0.01
WQM-104	11150	7.17	38.6	7247.5	2222	191	2466	1666.7	1.44	285	367	1665.2	12	466.4	0.11
WQM-105	8840	7.09	36.5	5746.0	2311	173	1765	1550.0	1.57	310	373	999	11.4	349.8	0.06
WQM-119	1226	7.98	31	796.9	336	226	137	165.0	0.66	66	41	130.5	2.5	74.36	0.03
WQM-138	4460	7.64	33.4	2899.0	1298	1041	728	580.0	0.84	289	140	530.7	38.5	1.76	0.14