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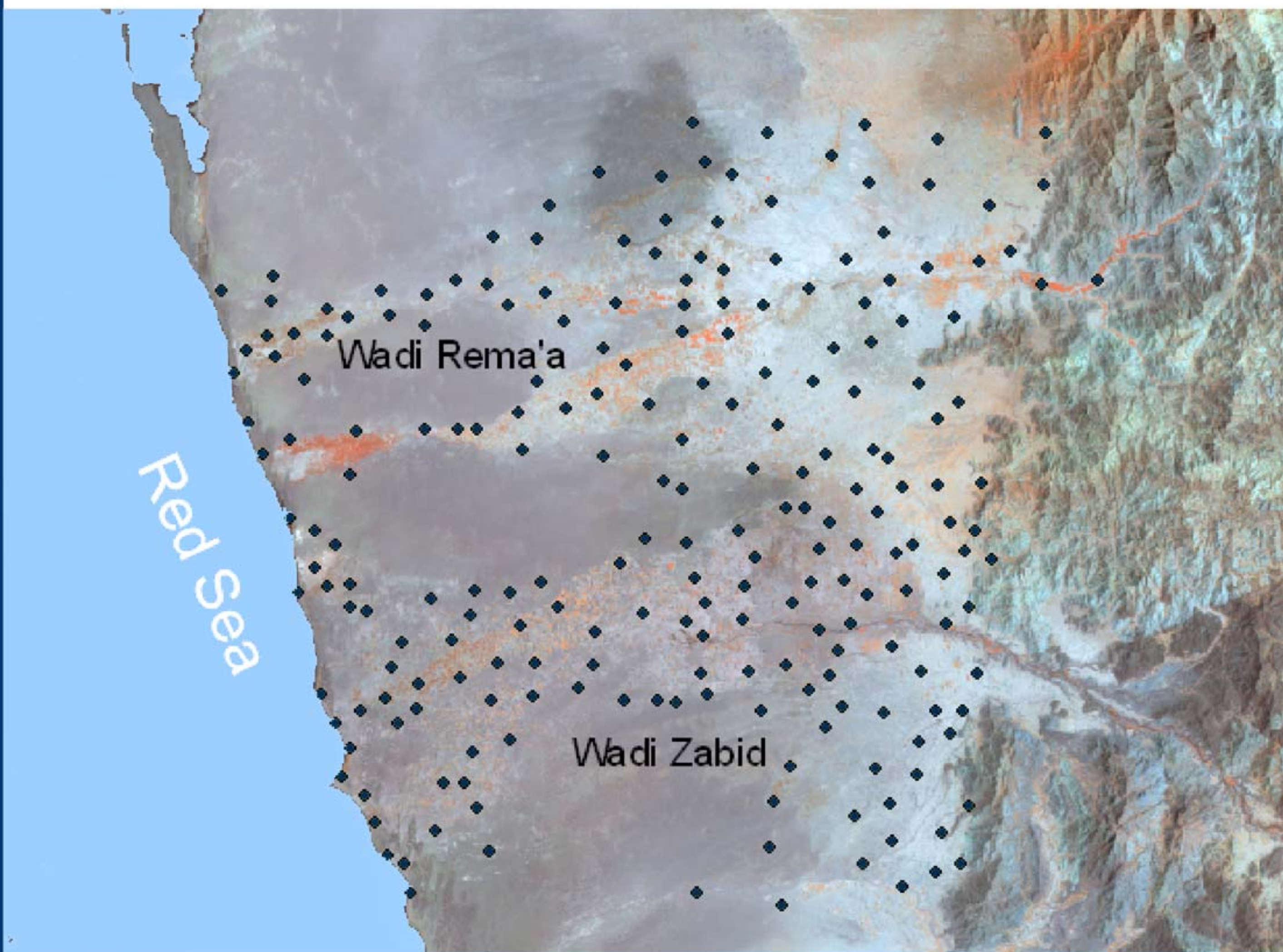
National Water Resources Authority

REPUPLIC OF YEMEN
MINISTRY OF WATER AND ENVIRONMENT
NATIONAL WATER RESOURCES AUTHORITY
Studies and Planning Sector

TIHAMA WATER RESOURCES MANAGEMENT

WADI ZABID & WADI REMA'A
Water Quality

Final Report



Sana'a March 2009

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Acknowledgement

This study was carried out under the responsibility of senior staff from National Water Resources Authority (NWRA) headquarter in Sana’a and the NWRA Hodeidah branch with cooperation with Tihama Development Authority laboratory which analysed the water samples collected from Wadis Zabid and Rema'a.

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Eng. Ali Kasem M. As Sayagh

Study Supervisor

1- Background on the study Area

1-1 Introduction

In many groundwater assessment studies, evaluation of the quality of groundwater is as important as the quantity, in as much as the usability of groundwater available is determined by its chemical, physical and bacteriological properties. A program of study of the quality of groundwater in the Zabid water resources management district envisages field observations regarding the source and environment of groundwater occurrence, source of pollution and other related aspects having a bearing on the quality of groundwater.

Zabid water resources management district (WRMD) suffers from over exploitation as well as mismanagement of the water resources in the district. According to the last well inventory for the district which achieved by NWRA in 2006, there were about 7572 operational water points in the district , the total abstraction from these wells are 706,640,496 m3.

The over exploitation in the district causes to deterioration of the water quality in the plain and especially in the down stream areas.

According to the National Water Resources Authority management regions and districts, Zabid water resources management district is one of seven water resources management districts in the Tihamah plain.

Hydrogeologically Zabid area was categorized by DHV as (Zabid hydro geological province), and it was the seventh province among the eleven hydro geological provinces in the Tihamah plain (TBWRS, DHV, 1988).

Agriculturally Zabid water resources management district is located in the Southern Tihamah agricultural region according to Tihamah development authority (TDA) categorization which divided the Tihamah plain into three agricultural regions : northern, middle and southern.

Geographically Zabid water resources management district is represented in six map sheets scale 1: 50,000 (1443 D1, 1443 C2, 1443C1, 1343 D3, 1443 C4 and 1443 C3).

The hydrochemical and groundwater pollution study was completed by the National Water Resources Authority-HQ with participitaion of staff from TDA and the NWRA branch in Hodeidah.

The study has investigated the quality of groundwater resources of Tihamah Basin, and outlined the causes behind their current degradation trends. The study provides useful tools to predict the outlook of future water quality in the region.

1-2 Location

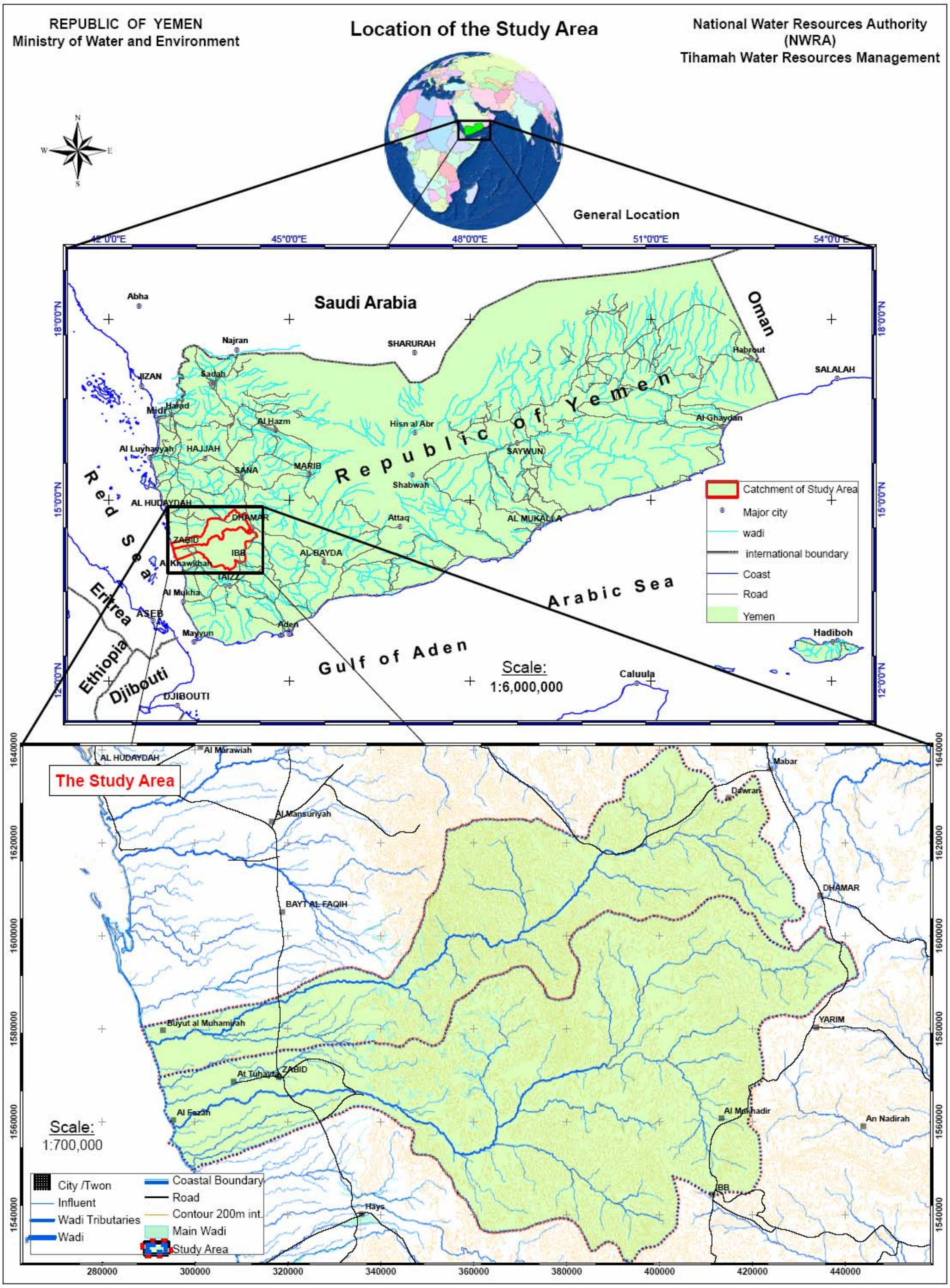
Figure 1 shows the location of Zabid water resources management district, which lies in the southern part of Tihama coastal plain which is located in the western part of the Republic of Yemen. Zabid water resources management district lies between latitude (UTM=346,000m , 288.000m E) and longitude (1,600,400m , 1,548,000m N). The total area of the project (Wadi Zabid and Wadi Rema'a coastal plain) is about 2242 km^2 or 224,200 hectare (DHV,TBWRS, 1988), The average length of Zabid district from the North to South is about 50 km, while the average width is about 45 km.

1-3 Population and Economic Activities

According to the final Results of Population, Housing & Establishment Census, 2004 implemented by central statistical organization (CSO), the total population of the project area reaches 412,248 persons. The population in urban communities (province centers and secondary towns) is about 103062 persons (25%) while the population in rural communities is about 309186 persons (75%) and all the population is concentrated in an area of 184 km2.

Agriculture is the major activity for the population of the Zabid water resources management district, 70-75% of the population is engaged in agriculture.

Figure 1:Location of Zabid water resources management district



About 57,000 ha of irrigated area depend on groundwater and 15000 he by spate-irrigation while 552000 he are rainfed. The main cash crops in the district are banana, mango and date palms.

The average net incomes from irrigated area are about 250000 YR / hectare. The secondary activity is livestock production especially in the middle area. The approximate total number of livestock is about 500,000 (2008).

There is a general trend towards mixed farming (crop and livestock production) on the majority of the farms (HWC, 1992).

Livestock is a relatively important source of cash income for farmers especially for those situated down streams of Wadis, groundwater irrigated areas and in the rain fed areas.

Farmers in the deep groundwater irrigated areas depend on the livestock incomes to buy, fuel for their pumping equipment, while the farmers in the rain fed areas largely mainly depend on the livestock incomes due to the low incomes from the cultivated crops.

Off-farm incomes plays an important role for Farmers in downstream Groundwater irrigated areas, rain fed areas and bare rangeland areas. This income is generates from the following sources:-

1. Local off-farm incomes such as off-farm agricultural labor, honey processing, fishing, transportation equipment (trucks, buses, vehicles, motor cycles), small shops and building labors
2. Immigration remittance form of the incomes, generated internationally in Saudia Arabia and locally (nationally) in big cities (Hodeidah, Sana'a) and semi urban towns (Zabid, Hussayniah ...etc)
3. Government jobs (teachers, army & police personnel and other official jobs) and government social welfare

1-4 Catchment's Area

The catchment area of Zabid water resources management district includes two major Wadis : Wadi Zabid and Wadi Rima'a.

Administratively the catchment area is situated (partially) in three governorates : Dhamar, Raymah and Ibb Governorates.

The central valley receives the lowest quantity of annual rainfall (about 300 mm) in the catchment area.
The catchment area can be divided into two upper catchment areas:

- The north-eastern upper catchment area extending as far as the surroundings of Dhamar and Raymah Governorates at an altitude of (2400)m. This sub catchment area has a relatively dry climate (annual rainfall is 400 mm). It contributes mainly to the base flow and floods for Wadi Rima'a
- The south-eastern upper catchment extending as far as so-called green Yemen region around the city of Ibb, Gabal Sumarah and Al-Odien province. Agriculture in this catchment is very intensive and the rainfall is sufficient (1000 mm). The rainfall is more evenly distributed over the year than in the more arid parts of Yemen

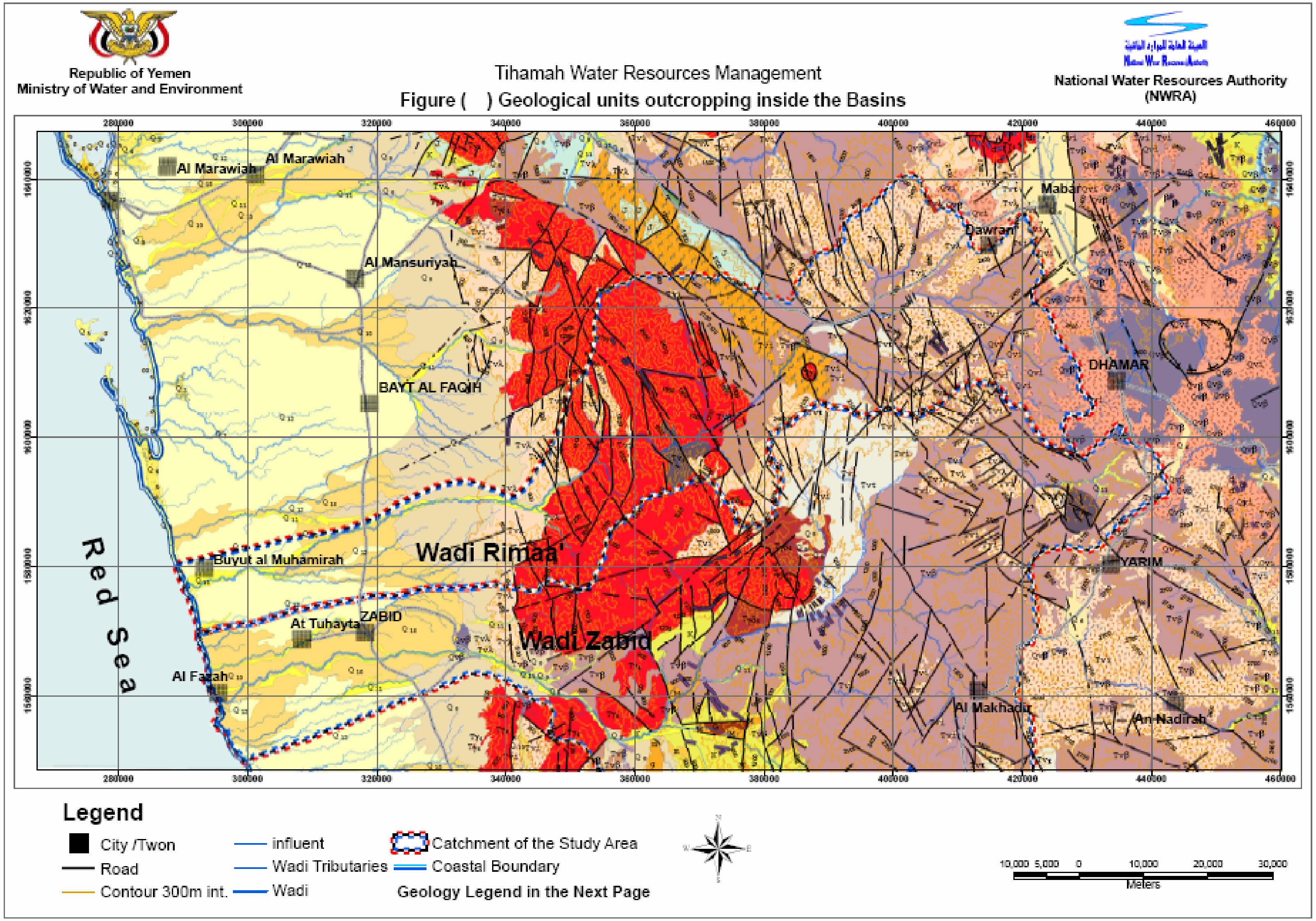
1-5 Geology and Hydrogeology

The aspects of the geological and Hydrogeological Zabid water resources management district have been studied by several consultants during the period from 1970-1988 (Figure 2), for both the catchment area and Tihama coastal plain. This project study will focus only on Tihama coastal plain.

Stratigraphy:

The stratigraphy of Zabid water resources management district comprised entirely of sedimentary deposits which are over (200 m) thick (B.L morric).
The subsurface geology forms basically a continue which can be divided into two broad faces based on grain size, which decreases west-wards as a factor both of degree combination of sediment transport capacity as the Wadi spate is dissipated on route to the sea.
Altogether four main physiographic units can be recognized within the land for the coastal plain.

Figure 2: Geological map of Zabid water resources management istrict



- Alluvial fan
- Alluvial plain (Coarse to medium subsurface deposits).
- Alluvial sand deposits
- Alluvial marine platform (medium to fine subsurface deposits).

Zabid alluvial aquifer :

Zabid water resources management district is underlain by an extensive alluvial aquifer which ranges in depth from 0-50m in the east, adjacent to the foothills to 200-300m at the coast.

The evaluation of the aquifer has been mainly controlled by the tectonics associated with development of the Red Sea graben. The aquifer comprising of cobles gravel, sand salt and clays. (DHV, M.R.,1988).

The aquifer is divided into two layers, the upper part is more permeable with a thickness of 100m and a lower layer with less permeability, extends to a depth of 350m.

The occurrence of the upper layer is associated with the drainage courses of the Wadi Zabid and Wadi Rima'a. The coarse grained deposits are inter-bedded with lenses and layers of intergrained motival. This is often characteristic of aquifers formed from coalescing alluvial fun deposits.

Locally this produces semi-confined conditions, but the aquifer as whole acts as an unconfined system.

Aquifer production:

The depth to water level varies according to the location:

- Near the foot hills in the east the groundwater level varies from 0-50 meters below ground level
- In the middle part of the district the groundwater level ranges from 70-120 m below ground level
- Near the coast the groundwater level ranges from 100-300 m below ground level.

The depth to groundwater level has been declined during the past 20 years (1985-2005) by about 30 meters especially in the first and second areas where extensive groundwater irrigation areas with an average decline of about 0.5-1.5m per annum.

Hydraulic gradient:

It varies from area to area according to location. In the alluvial fan areas it is about 0.01, in the central plain area it is about 0,005 and in the coastal zone is 0,001. The changes in gradients is mostly determined by, an increasing aquifer thickness, by sea level and the coast.

Hydraulic conductivities Varies conciderable, reflecting the complexity of the aquifer system. The ratio of vertical permeability and horizontal along Wadi Zabid and Wadi Rima'a channel varies from 0.007 to 0.12, and the ratio of permeability along the Wadi coarses to the permabilities normal to the Wadi course varies from 1-3 m/d (HWC).

Permeability of more than 60 m/day mostly occurs at the top (30-10m of the aquifer) gradually declins to about 30m/day at depths of about 100m.

Transmisivity :

Base on pumping test results, well logs and specific capacity data carried in the area by DHV (DHV, 1988), the broad range of transmisivity value was estimated as follows:

Fan areas less than 500 m^2/d

Central plain 500-1000 m^2/d and

The coastal zone 1000-2500 m^2/d

Specific capacity :

In the area, the specific capacity ranges from 1-5 l/s/m with higher values at the Wadi channel and the coastal areas 1-8 l/s/m.

Specific yield :

According to DHV (DHV, 1988) mean value was 13%, although values ranging from 1-23% are reported from different surveys. However these are assumed values (HWC, IV volume , 1992).

1-6 Climate

Zabid water resources management district is an arid district typical of the Tihama region. It receives small amounts of rainfall during summer, with higher temperatures prevailing throughout the year. The Zabid W.R.M.D is in the vicinity of three large bodies of water which effects the climate**:** The Indian Ocean, The Red Sea and the Mediterranean Sea. They are sources of moisture for the passing air masses and they have an impact on the general atmospheric circulation (WRAY-35).

The presence of the Red Sea produces the so called Red Sea convergence zone (RSCZ) which contributes to the spring season (March-May). The light rains sometimes observed during the winter months of December and January are attributed to a similar convergence effect around the Mediterranean Sea's. Mansonal winds rain that creat the inter tropical convergences zone (ITCZ) effect during summer causing the main rainy season. (July-September).

1.6.1 Rainfall :

Rainfall in Zabid water resources management district increases east ward due to the geographic effect of the mountainous areas. The rain fall patterns are influenced by both the Red Sea convergence zone effect (RSCZ) and the inter tropical convergences zone (I.T.C.Z) effect, which produce to main rainfall periods, one from March to May and the other from July to September.

Mean annual rain fall amount varies from < 100 mm in the western coastal areas to about 500 mm in the eastern foothills areas (DHV,1988).

Rainfall observations and measurements began in 1970 in the main Wadis (Zabid, Rima'a) and in the catchment areas of those Wadis. The annual rainfall stations have been established for different objectives by various consultants who carried out water resources studies in Zabid district from the period 1970 to 1984. There was a shift towards automatic rainfall stations during the implementation of Tihama Basin Water Resources Study (TBWRS) 1984-1988 and these stations are still operated by Tihama Development Authority (TDA).

The catchment area of Zabid water resources management district is an arid to semi arid region and it receives more rainfall than the Tiham plain due to the geographic effect of the mountainous areas (high elevation). The catchment area receives rainfall in two seasons : spring and summer.

Mean annual rainfall amount varies from < 500 mm in the middle catchment area and in some parts of the upper catchment area (Dhawran Anis, Dhamar) to 1000 mm in upper catchments area (Ibb, Gibal Raymah). The rainfall stations were established at the same time as the rain stations in the lower plain, and were automatizide and they still observed by TDA (Table 1 & figure 3, 4).

Table 1: Rainfall station records in Zabid W.R.M.D

Stations	**UTM-East**	**UTM-North**	**Mean annual rainfall (mm)**
Al Mahat	316625	1581596	199.9
Zabid	321929	1568649	209.3
Al khmah	330986	1577807	288.3
Yarim	433489	1581012	330.4
Basat	323844	1585232	359.9
Al Duminah	331061	1588870	361.2
Wadi Al har	417390	1605026	376.2
Najd Alhadad	415607	1608718	380.5
Al Sinam	420994	1608700	386.1
Al jarubah	330899	1564899	398.8
Al masna'ah	415645	1619780	416.4
Al Mishrafah	345441	1588777	417.6
Hamam Ali	408465	1619806	488.1
Al GhaWadir	338251	1588823	521.5
Gabal Alshark	388712	1618044	532.2
Al dalil	411846	1560801	711.1
Ibb	411795	1546053	909.3
Al Odien	400979	1542405	948.9

Figure 3: Peizometric map for Mean annual rainfall in Zabid WRM D

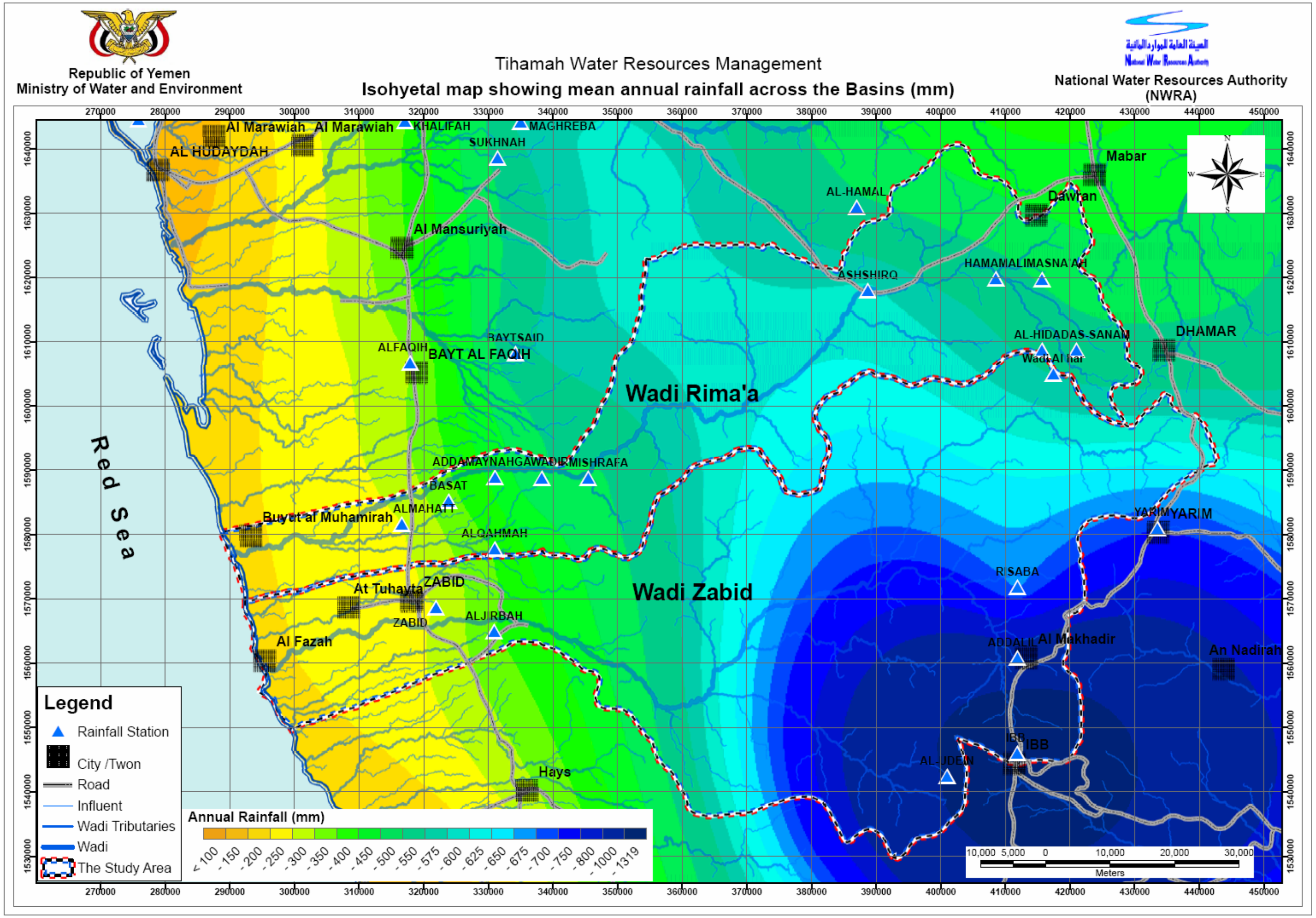
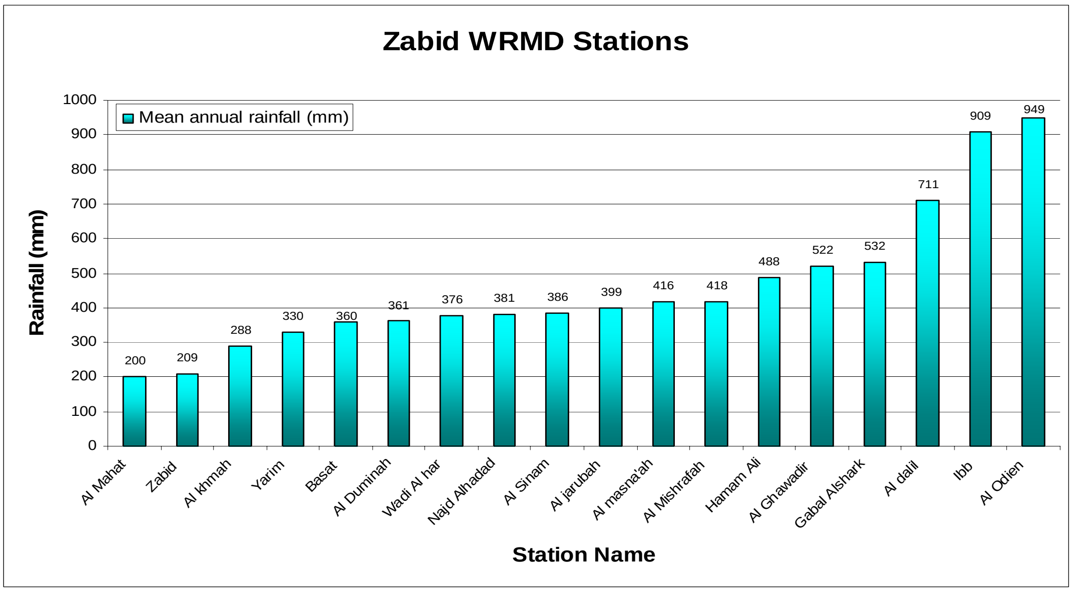


Figure 4: Mean annual rainfall in Zabid WRM District

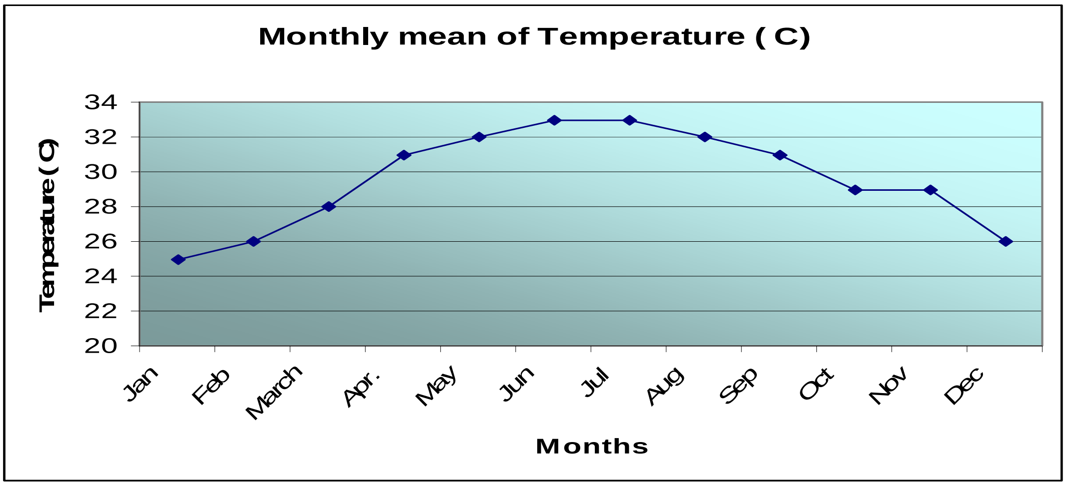


1.6.2 Air temperature :

Zabid district is an arid district with high air temperature. The air temperatures vary according to months of the year and the altitude. During the months from May to August the temperature is very high where the maximum air temperature may reach 40o C, while the temperature from September to April becomes moderate at about 18oC. Air temperature in Zabid district has been observed since 1970 and 1978 by two meteorological station located in Zabid town and Al Jarubah farm (Al-Gerbah hydrometeoroligical station).

The annual average of air temperature is 29.6C^{o}. Figure 5 illustrate the monthly mean for air temperature in the study area.

Figure 5: The monthly mean for air temperature in the study area



1.6.3 Evaporation :

Evaporation values in Zabid water resources management district were calculated using the Penman reference which include the following parameters from the Al-Gerbah Hydrometeoroligical station:

- Mean monthly temperature
- Mean monthly humidity
- Sunshine duration
- Wind speed

Seasonal variation ranges from 4-7 mm/day and the annual total is about 2000 mm (DHV, 1988).

1.6.4 Humidity:

Humidity varies throughout the year. The humidity and other parameters in the study area were measured using the Zabid Hydrometeorological stations. The mean monthly humidity is 60-75%. Figure 6 illustrate the mean monthly of humidity, while Table 2 shows the different parameters which are measured by the Al Gerbah meteological station .

Figure 6: Mean monthly of Humidity in the study area

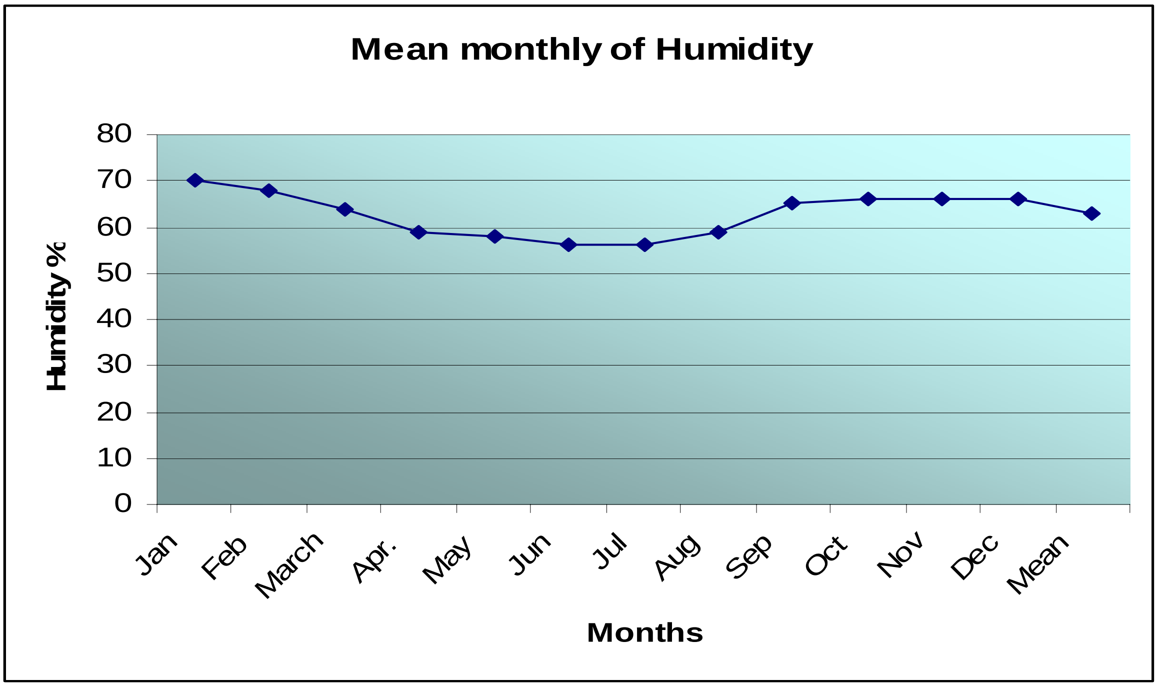


Table 2:Climate data (Al Gerbah meteological station from 1970-1986)

Month	Temperature (Deg. C)	Humidity %	Sunshine duration (hr/d)	Wind speed (m/s)
Jan	25	70	7.1	1.2
Feb	26	68	6.9	1.3
March	28	64	6.5	1.5
Apr.	31	59	8.1	1.6
May	32	58	7.8	1.7
Jun	33	56	6.6	2
Jul	33	56	4.6	2
Aug	32	59	5.8	1.4
Sep	31	65	6.6	1.1
Oct	29	66	8.3	1.1
Nov	29	66	8.9	1.1
Dec	26	66	7.9	1.1
Mean	**29.6**	**62.8**	**7.1**	**1.4**

1-7 Surface water

Surface water in the Zabid Water Resources Management district consist of wadi flows which reflect the seasonal rainfall pattern in the catchment area.

The catchment area of the Zabid district includes two main Wadi catchments - Zabid and Rima'a, these catchment can be divided into upper, middle and lower sub catchments. The lower part of the catchments are located in the Tihama plain.

The flow regime is determined by the rainfall and the groundwater storage /out flow in the middle and upper catchments.

The contribution of those components determine the flow down stream. The Tihama plain (lower, sub-catchment) is considered to be minimal .

The area of the upper and middle sub catchment is 8757 km^2.

The area of the lower sub catchment (Tihama) = 2242 km^2.

The total catchment area = 10999 km2. (HWC, & DHV).

Discharged volumes:

Monitoring and measurements of volume discharge in both main district Wadis (Wadi Zabid and Wadi Rima'a) started in 1970 and in 1975 by various consultants who worked for the TDA wadis development projects. These monitoring stations are automatically and still tacking place in two locations by TDA (Alkolah Station in Wadi Zabid and Almishrafah station in Wadi Rima'a).

Surface water flows are extremely variable. Long period of low flows may be alternated by the occurrence of floods with a short duration but a high discharge.

Discharges during low (Base) flow conditions are typically in the order of 1-5 m^3/sec. During the floods the discharges may rise to several thousands m^3/sec. (DHV, T.R.2).

High flood peaks are occurs in the months April, July and August. The wettest season is usually July to October where the Wadis surface flow discharge volumes reach two third of the total annual flow volumes.

Floods in comparison with base flow volumes are in order of two thirds of the total flows. The water from the Wadis that is not lost by evapo-transpiration in the spate irrigation zones feeds the groundwater system of the district and continues moving towards the sea underground. In the past this water was finally discharged into the Red Sea (by groundwater outflow).

Irrigation practices have created the second important discharge component. The evapotranspiration of irrigation crops and sediment transport tends to be extreme during high flows.

2- Hydrochemistry

2-1 Introduction

This objective of this chapter is to provide information on the characteristics, water types, genesis and suitability of the water resources in the study area for domestic and agricultural purposes. The different types of pollutants, possible sources and impacts on the ground water resources will be highlighted. To achieve these purposes representative samples from the dug wells, borehole wells and dug/borehole wells, Figure 7. All the samples were analyzed for the major and minor ions. The EC, pH, DO and Temp were measured for all the samples. The hydrochemical and groundwater pollution study was completed by the National Water Resources Authority staff with the participation of some TDA staff and the NWRA branch in Hodeidah.

2-2 Specific objectives of the study

The specific objectives of the study are summarized as follows:

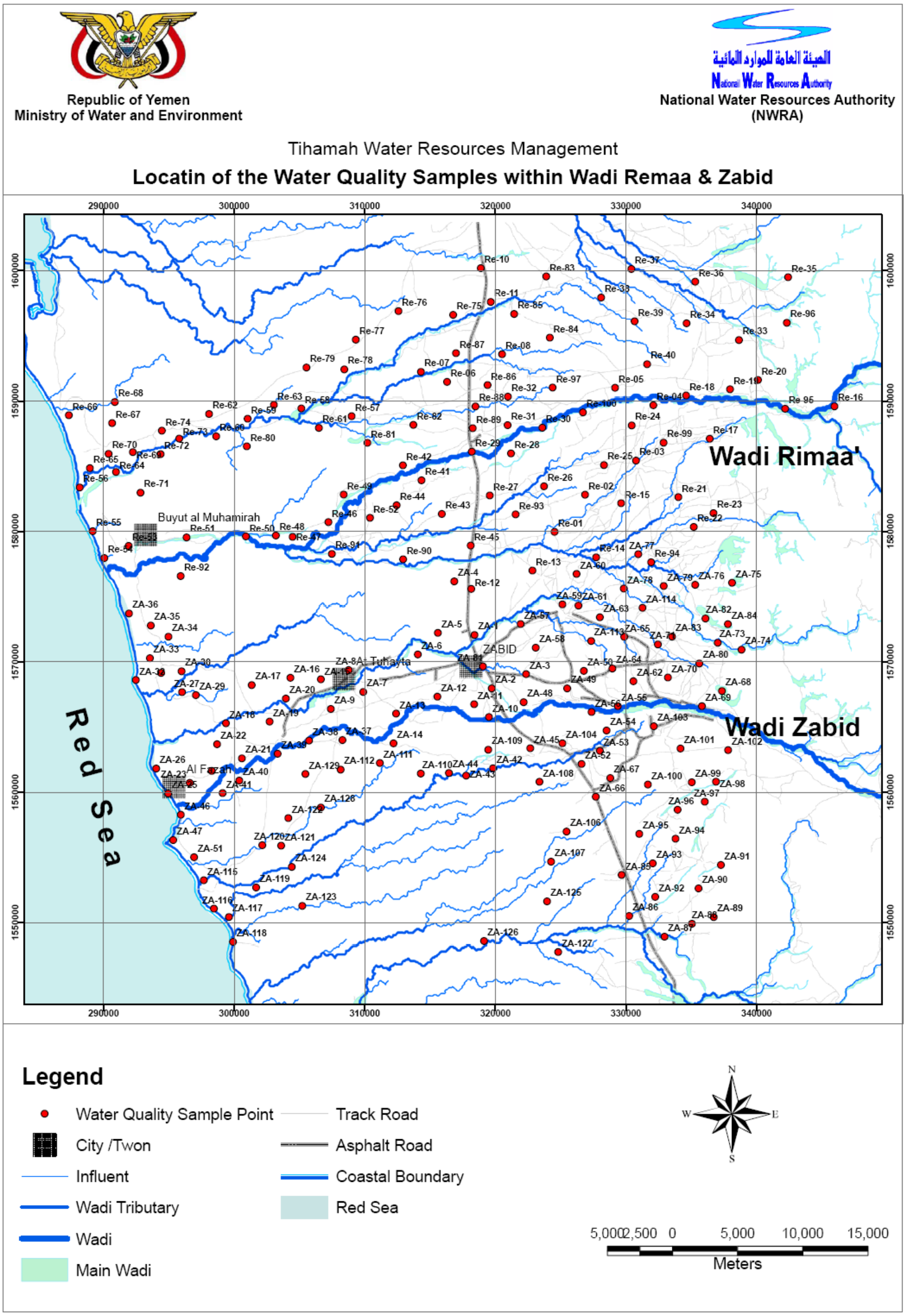
1- Update and obtain information about the hydrogeochemical properties of the main water bearing strata
2- investigate the origin and spatial spread of brackish and saline waters
3- Groundwater quality in relation to use
4- Examine the vulnerability and exposure of the water resources to pollution

2-3 Work carried out in Wadi Zabid & Wadi Rema'a

To achieve the objectives of the study, the six fundamental survey preparation and field research activities were carried out and 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
- Data analysis and interpretation as a basis to formulate recommendations.

Figure 7:Location of the water quality samples in the study area



The six activities have been implemented in three sequential stages:

- Preparation work (2.3.1)
- Field implementation (§2.3.2)
- Analysis & data processing (§2.3.3)

2-3-1 Preparation work

2-3-1-1 Review and quality-check of available hydro- & 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 Zabid and Rema'a.

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

For sample collection purposes, there are many criteria for selection of 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 two Wadis were in 2006-2007)
- There is information on pump depth and total depth for water points
- The spatial distribution for samples on all Wadis
- There is information on the geological structure for water points.
- There is advice from the well inventory survey

The selected wells have 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 superficial 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 Study area: Wadi Zabid & Wadi Rema'a

The groundwater quality study has covered two major Hydrological Basins – Wadi Zabid & Wadi Rema'a that cover over 2242 km^2.

2-3-2-2- Sampling and laboratory analysis

The chemistry survey team for this project was based in Hodeidah, where the TDA laboratory was established. The chemistry team was formed as a combination of NWRA and TDA staff (Annex I). The field leader was responsible for managing the daily collection of groundwater samples and supervising the laboratory analysis. The team started fieldwork on November 21, 2007 and ended it on January 2, 2008 .

2-3-2-3 Sample collection

In total, 229 samples were collected 129 from Wadi Zabid and 100 from Wadi Rema'a (5 samples were duplicates) Annex (II). These wells including 101 dug wells (45%), 96 dug /boreholes (43%) and 27 boreholes (12%). Sample locations and all characteristic are shown in Tables 3 and Figure 7.

Table 3 : Types of samples collected wells

Wadi	Dug	Borehole	Dug/Bore	Blank	Total
Zabid	75	18	33	3	129
Rema'a	26	9	63	2	100
Total	101	27	96	5	229

During sampling, the well owner was asked for any further information about the well, especially on the lithology, 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 Annex II.

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 Hodeidah, where they were analysed for EC and pH on the same day while other parameters were analysed the next day.

2-3-2-4- 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 (2005-2006) 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.

2-3-2-5 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 (EC), pH, dissolved oxygen (DO) and temperature.

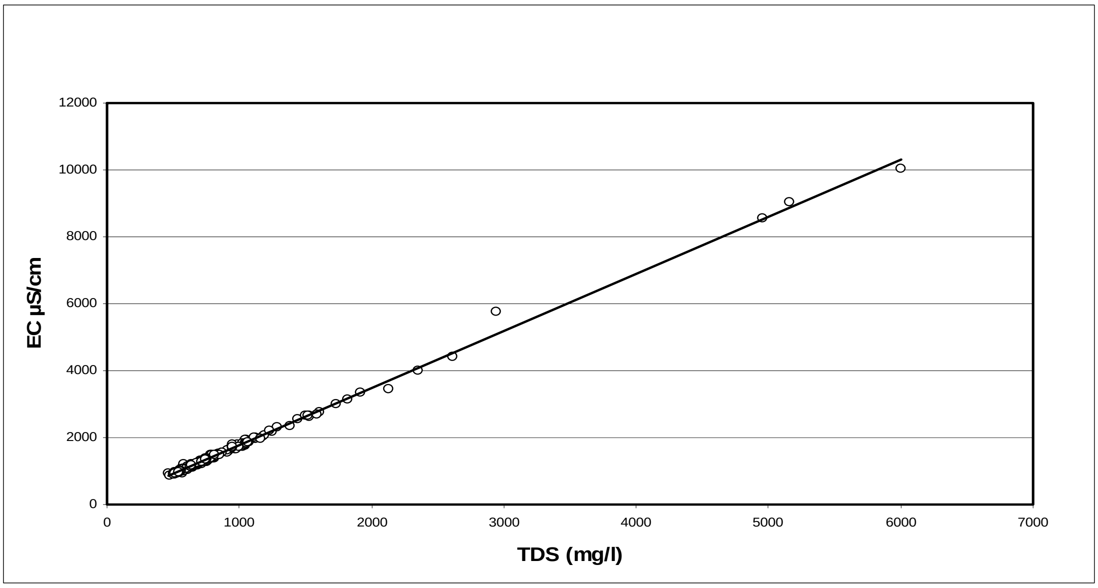
Electrical conductivity (EC):

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 resistivity (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 8, 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):

$$\textbf{TDS mg/L} = Ca^{+2}\ Mg^{+2} + Na^{+} + K^{+} + SO_4^{-2} + NO_3^{-} + 0.5\ HCO_3\ \textbf{(all in mg/L)}$$

Figure 8: The relation between the EC and the TDS values in the study area



EC varies between 747µS/cm and 17,790 µS/cm in Wadi Zabid with an average of 1558 µS/cm while it varied between 634µS/cm and 10,850 µS/cm in Wadi Rema'a with an average of 1287 µS/cm. This indicated that the salinity of the water in Wadi Zabid is higher than in Wadi Rema'a.

Figure 9 clearly illustrates the distribution and concentration of EC vales in the area. The general features of the conductivity pattern can by explained rather easily. The conductivity is normal for most areas, especially in the mid stream of Wadi Zabid and Wadi Rema,a. There are some areas with salinity anomalies in the north-east of Wadi Rema'a in Al Gumaeiah and Al Flash villages and south-east of Wadi Zabid in Al Qudasy (Al Jarahy) village. The map illustrates an generally east to west increase in the electrical conductivity. High salinity is clear in the north-east of the Wadi Rema'a in Al Marazekah and Ashwatbeh extending to the coast line to the south-west of Wadi Zabid in Al Fazah and Al Matinah. The increase of salinity in these areas may be caused by connate water of marine origin, recharge from coastal precipitation, or return flow from irrigation waters.

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.

Th pH value at 25C is pH 7 (neutral). An excess of hydrogen (H+) indicates an acid . Sample with corresponding pH value lower than 7. Conversely, an excess of hydroxyl ion (OH-) indicates an alkaline sample 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.

pH varied between 6.85 and 7.99 in Wadi Zabid with an average of 7.46, while it varied between 6.38 and 9.97 in Wadi Rema'a with an average of 7.38

Figure 10 clearly illustrates the pH concentration in the area, which is normal for all area.

Dissolved Oxygen

Solubility of oxygen in water depends on the partial pressure of oxygen in air, the temperature of the water, and the dissolved-solids content of the water (the higher the atmospheric pressure and the lower the temperature and conductivity, the more oxygen can be dissolved in the water).

Accurate data on the concentration of dissolved oxygen (DO) in environmental water resources are essential for documenting changes that result from natural phenomena and human activities. Sources of DO in water are related to atmospheric aeration. Many chemical and biological reactions in ground water and surface water depend directly or indirectly on the amount of available oxygen.

In the study area DO values are measured by DO instruments (meters and sensors). DO values range between 1.02 mg/l in sample no. ZA-080 (Aqby - Al Jarahy) and 5.46 mg/l in sample no. ZA- 036 (Wadi Al Mojailis) in Wadi Zabid and 1.55 mg/l in sample no. Re-22 (Wadi Kuhfah) and 6.57 mg/l in sample no. Re-004 (Ad Demnah Village) in Wadi Rema’a (Figure 11) .

Figure 9: Electrical conductivity map of the study area Samples

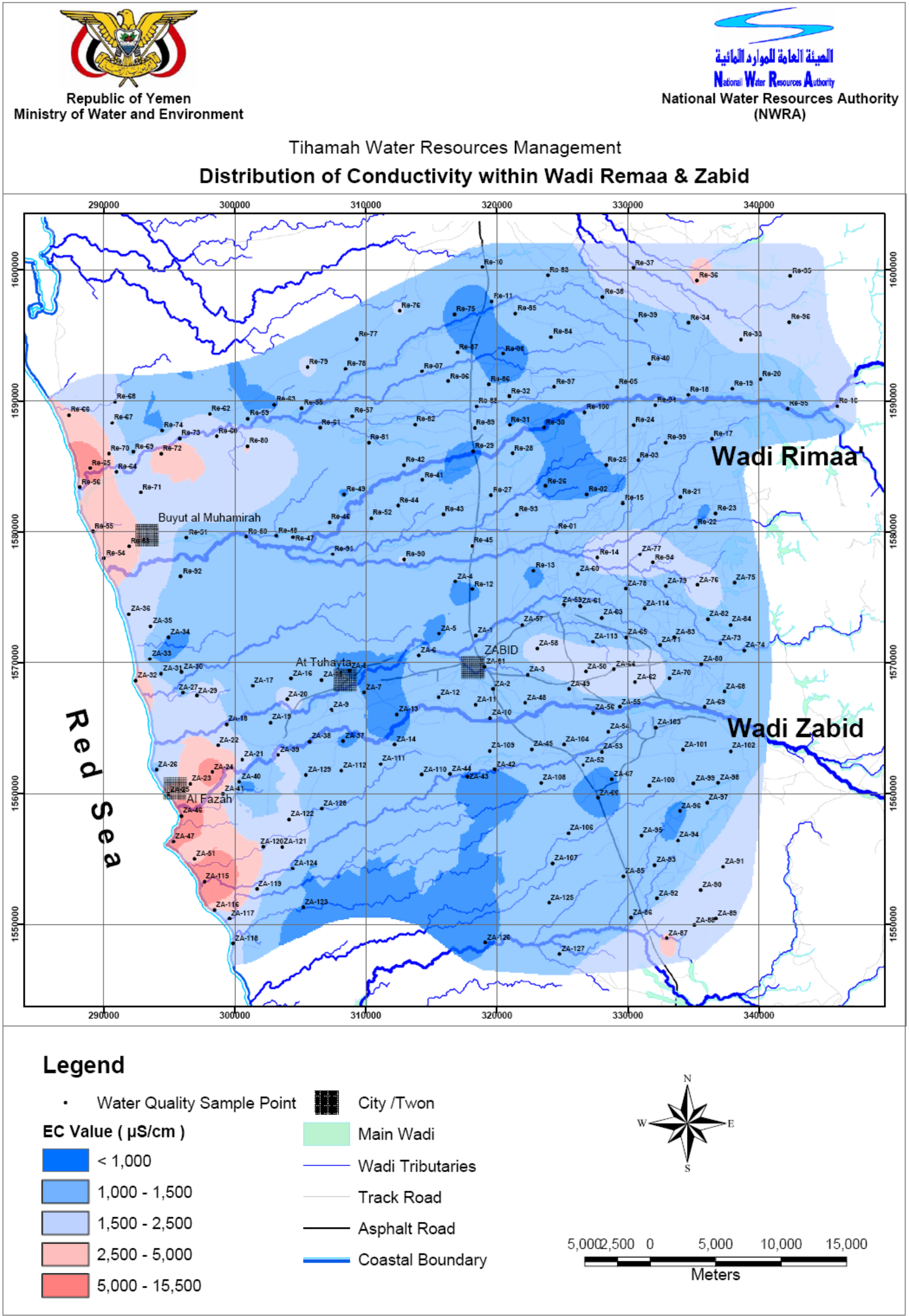


Figure 10: pH concentration of the study area Samples

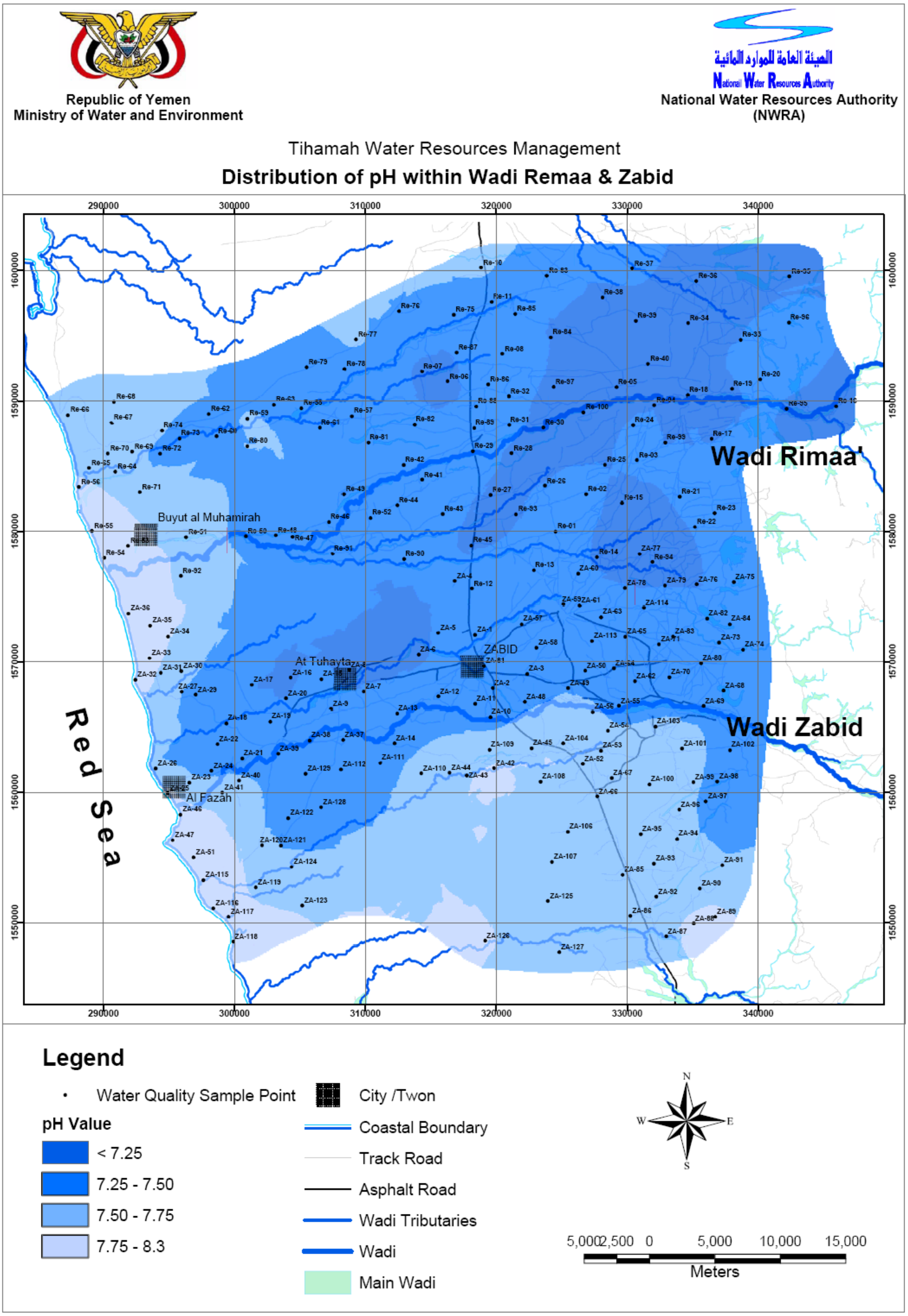
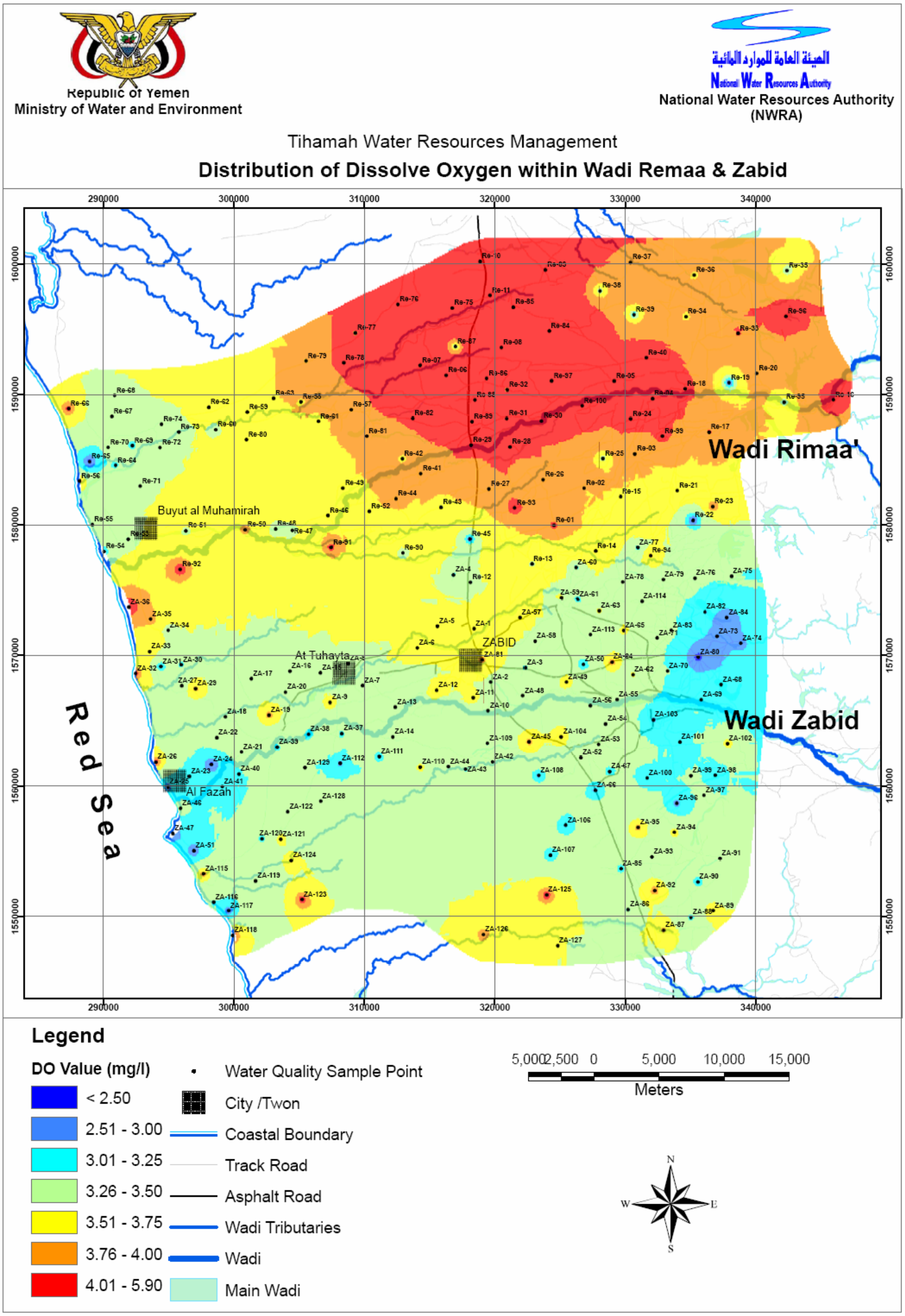


Figure 11: DO concentration of the study area Samples



Groundwater Temperature (^{o}C):

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 26.6 **^{o}C** and 34.7 **^{o}C** with average 31.6 **^{o}C** in Wadi Zabid and between 25.2 **^{o}C** and 36.7 **^{o}C** with average 32.3 **^{o}C** in Wadi Rema'a.

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 Tihamah Development Authority (TDA) chemical laboratory in Hodeidah. The methods used are shown below.

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
Potassium	(JENWAY)
Chloride	Titration with $AgNO_3$ or $Hg(NO_3)_2$
Sulphat	SulfaVer 4 with Barium
Nitrate	HACH Instrument
Fluoride	HACH Instrument
Iron	Atomic Adsorption

The results of analysis for Wadi Zabid and Wadi Reama'a Samples are expressed in Annex III

2-3-3-2- Quality of the analysis

Quality of the analyses was checked by three method:

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%. Samples with an error of more than +5% were re-analysed. Ion balance calculations and meq/L conversions for all samples are provided in Annex IV.

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/ calcuated 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) .

The quality of groundwater in Wadi Zabid and Wadi Rema'a depends upon several factors such as lithology and chemical composition of the aquifer material, climatic conditions prevailing during formation, and the quantity of water available in the aquifer and rate of circulation. The complex depositional, solution and decomposition processes result in different hydrogeochemical conditions in groundwater.

2-3-3-3- Chemical Constituents of Groundwater

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 (CaCO3), Limestone, Dolomite

CaMg(CO3)2, Gypsum Ca SO4-2H2O, Anhydrite CaSO4, 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 are $Ca\ (HCO_3)_2$, $CaCO_3$, and $CaSO_4$. Calcium is 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 study area, Calcium content ranges between 30 mg/l – 390 mg/l in Wadi Zabid while it ranges between 28-280 mg/l in Wadi Rema'a. Calcium in these concentration has no known effect on the health of humans or animals.

Figure 12 clearly illustrates the distribution the calcium concentration in the area , which is normal for all area except a small part in the south west of Wadi Zabid (south of Al Fazah Village).

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 study area, Magnesium content ranges between 11 mg/l – 360 mg/l in Wadi Zabid while ranges between 4.8-156 mg/l in Wadi Rema'a. Figure 13 clearly illustrates the distribution the magnesium concentration in the area which is normal for all the area except a small part in the south west of the area on the Red Sea on the same area which has a high concentration of calcium .

There are no known cases of magnesium poisoning. High oral doses magnesium may cause vomiting and diarrhoea.

Figure 12: Calcium Concentration of the study area Samples

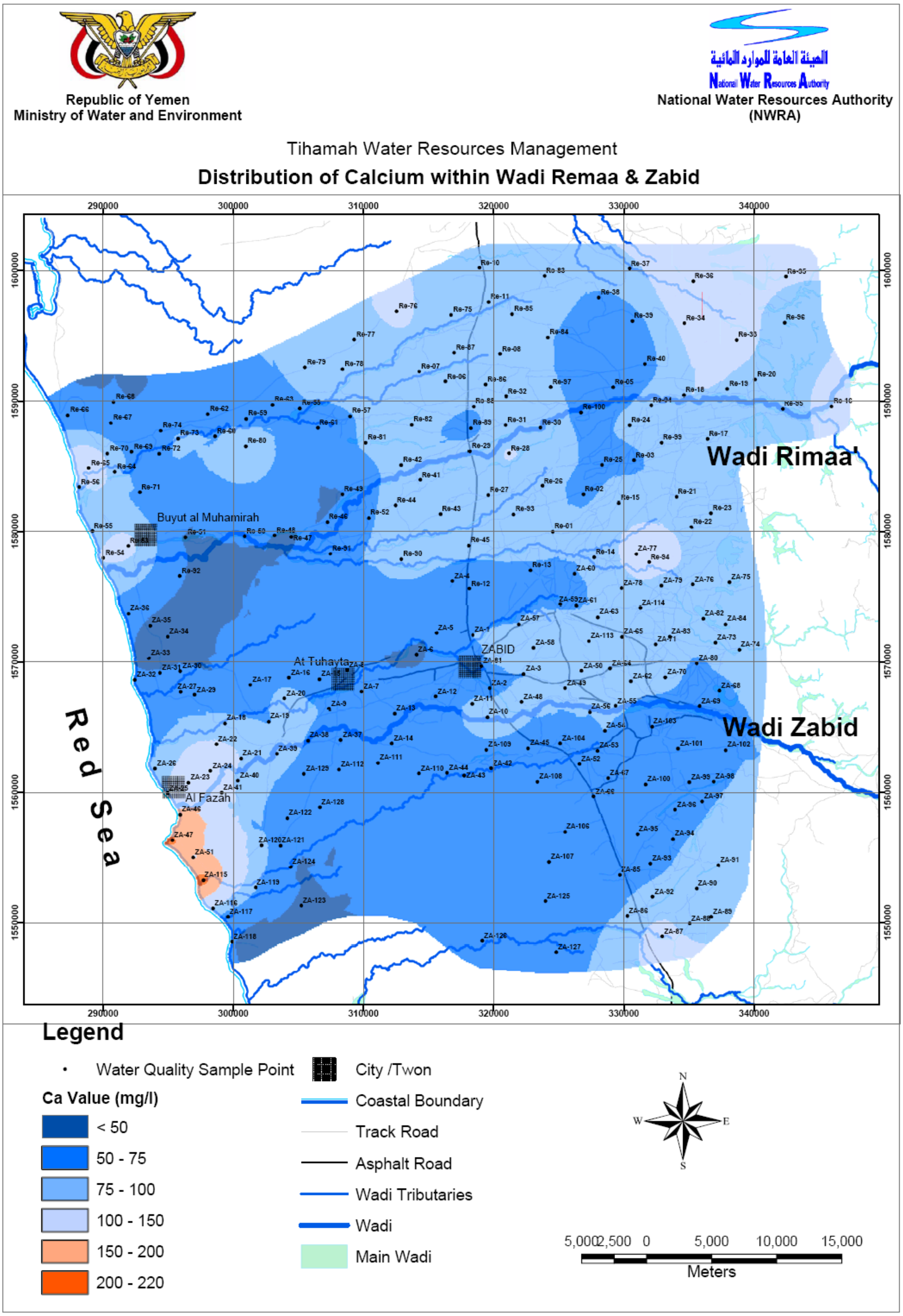
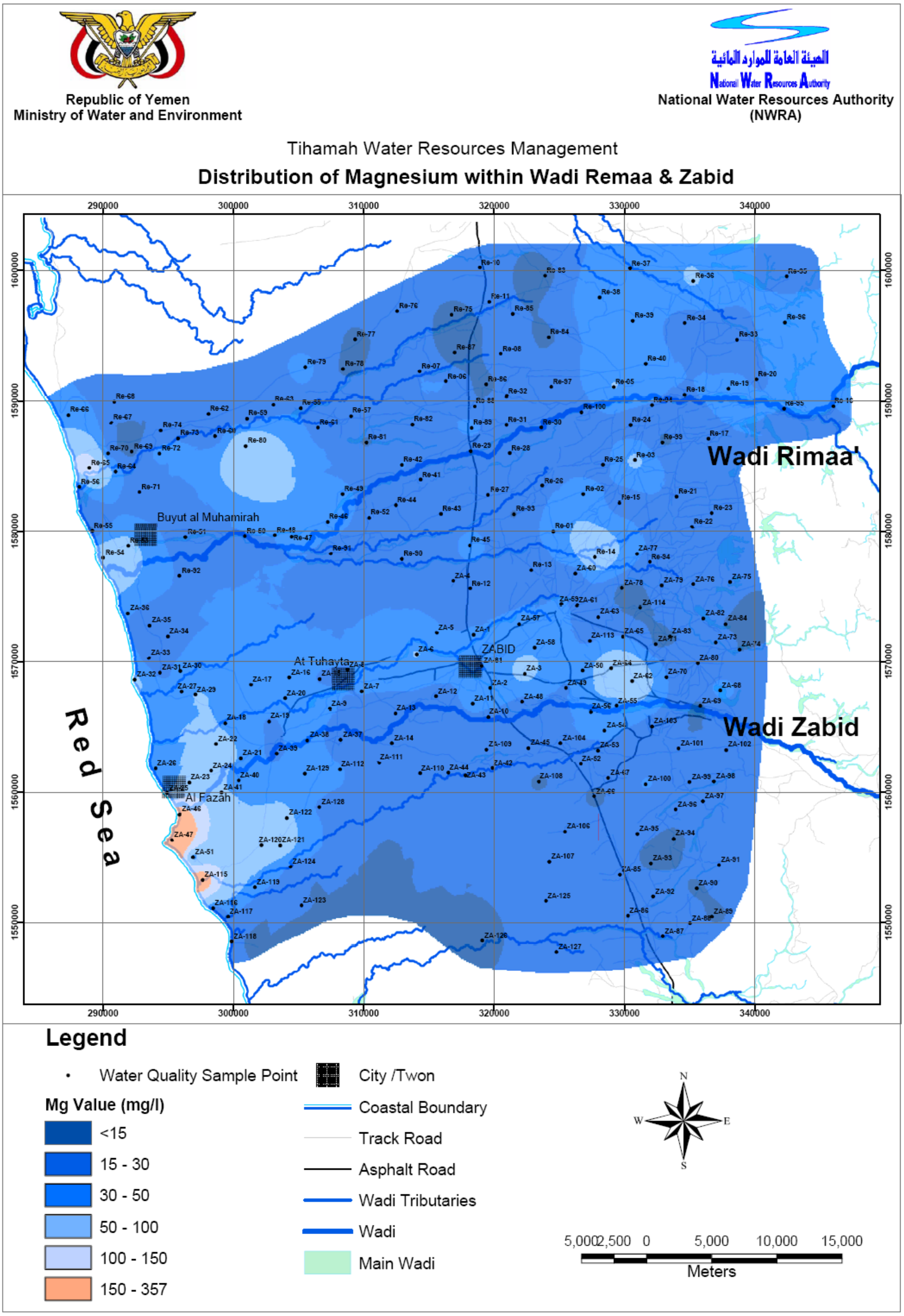


Figure 13: Magnesium Concentration of the study area Samples



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 betweens the sodium from the aquifer material and calcium found in water. The sodium salts found in water are Nacl and Na_2 SO_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 study area, Sodium content ranges between 90 mg/l – 2721 mg/l in Wadi Zabid while ranges between 69-1649 mg/l in Wadi Rema'a.

Figure 14 clearly illustrates increasing sodium element on the east-west of Wadi Rema'a in north west of Byut Al Muhaimerah and extended on the coast line to south-west of Wadi Zabid in Al Fazah and Al Matinah. 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 .

Potassium (k+)

Potassium is slightly less common than sodium in igneous rocks, but potassium is more abundant in all the local 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 K_2SO_4 .

In the study area, potassium content ranges between 1.2 mg/l – 47.11 mg/l in Wadi Zabid while ranges between <1-47 mg/l in Wadi Rema'a.

Figure 15 clearly illustrates the distribution the potassium concentration in the area which is normal for most areas however small areas along the coast have high concentration of sodium, which implies that the original for potassium is the marine water which usually contains about 400 ppm potassium.

Figure 14: Sodium Concentration of the study area Samples

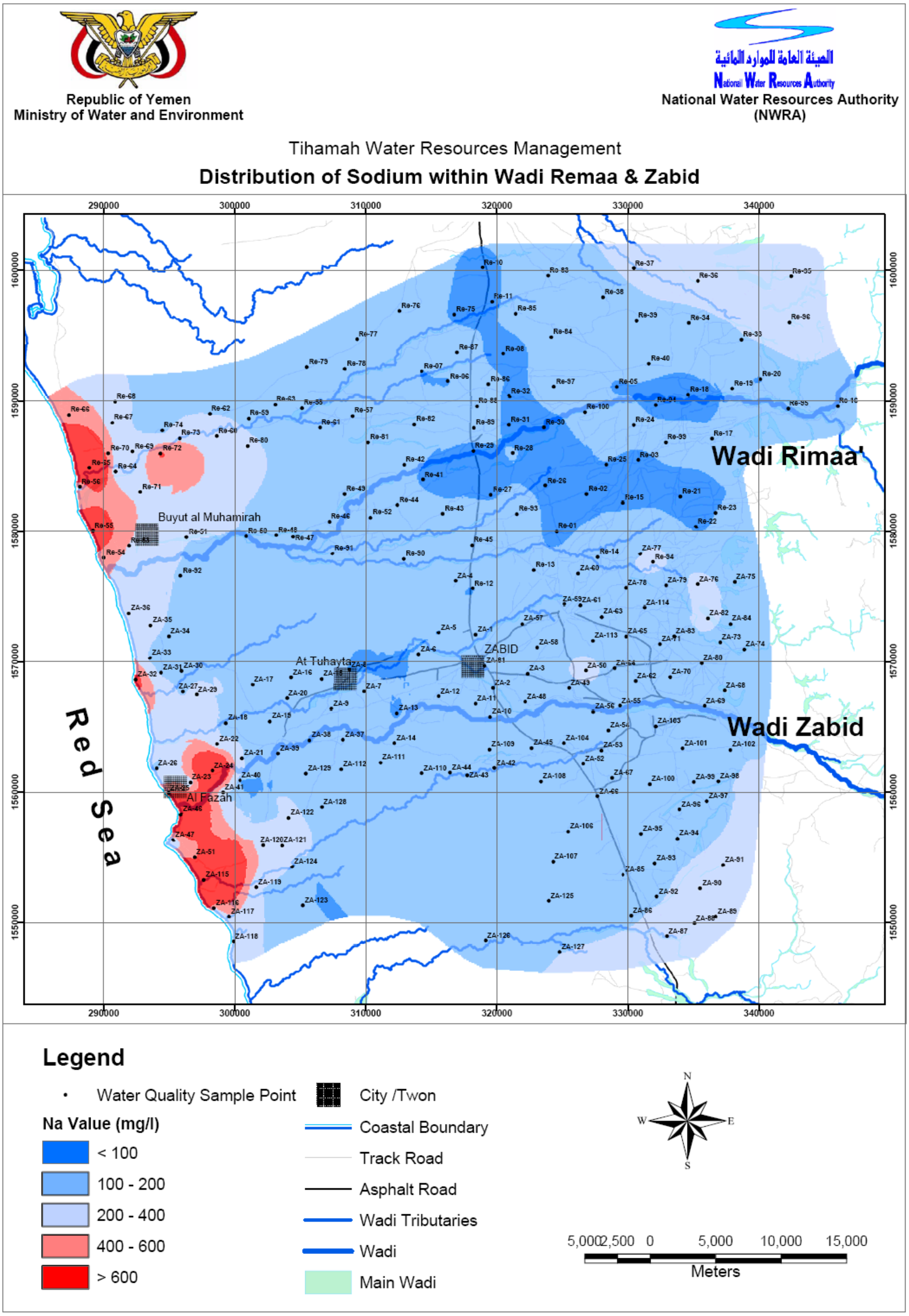
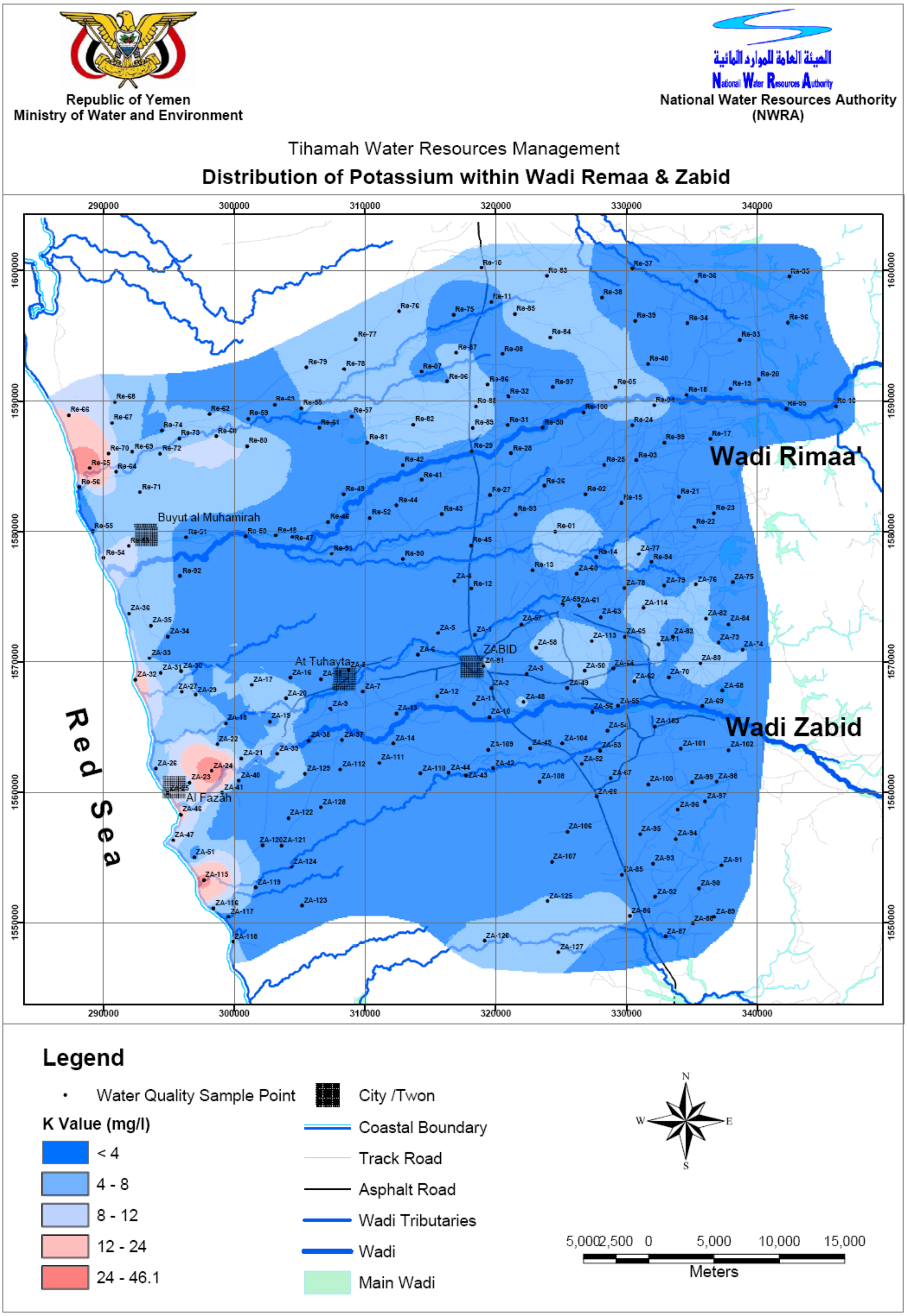


Figure 15: Potassium Concentration of the study area Samples



2- Major anions

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

The main sources of carbonate and bicarbonate is carbon- dioxide (CO2) from the atmosphere. Carbon dioxide is also released from the soil by organic decay and from plant respiration .

In Wadi Zabid carbonate was found in 8 samples and ranged between 7.5 to 75 mg/l while only one sample was found in Wadi Rema'a and was 15 mg/l.

The concentration of bicarbonate in the Wadi Zabid and Wadi Rema'a ranges between 244 mg/l – 976 mg/l..

Figure 16 shows the distribution of the bicarbonate concentration in the study area. Four areas contain a high concentration of bicarbonate in north east, north west, west on the coast and in the central area near Zabid city.

The high concentration of the Bicarbonate in the north east of Wadi Rema'a and east Wadi Zabid is a result of recharge in this area especially as is situated near the main tributaries of both Wadi Zabid and Wadi Rema'a.

Sulphate (SO_4^-)

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. This sulfides such as pyrite) are oxidized to yield Sulphate ions which are carried off in the water (Hem 1970) .

In the study area, Sulphate content ranges between 24 mg/l – 432 mg/l in Wadi Zabid (there is one abnormal sample with a sulfate concentration of 2016 mg/l) while values range between 26 mg/l -411 mg/l in Wadi Rema'a.

The Sulphate concentration map (Figure 17) shows that the entire area is normal except a small part in the south west of Wadi Zabid in Al Sakf village on the Red Sea.

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. In the study area, the chloride contamination increases closer to the coast especially in the down stream (figure 18).

Figure 16: Bicarbonate Concentration of the study area Samples

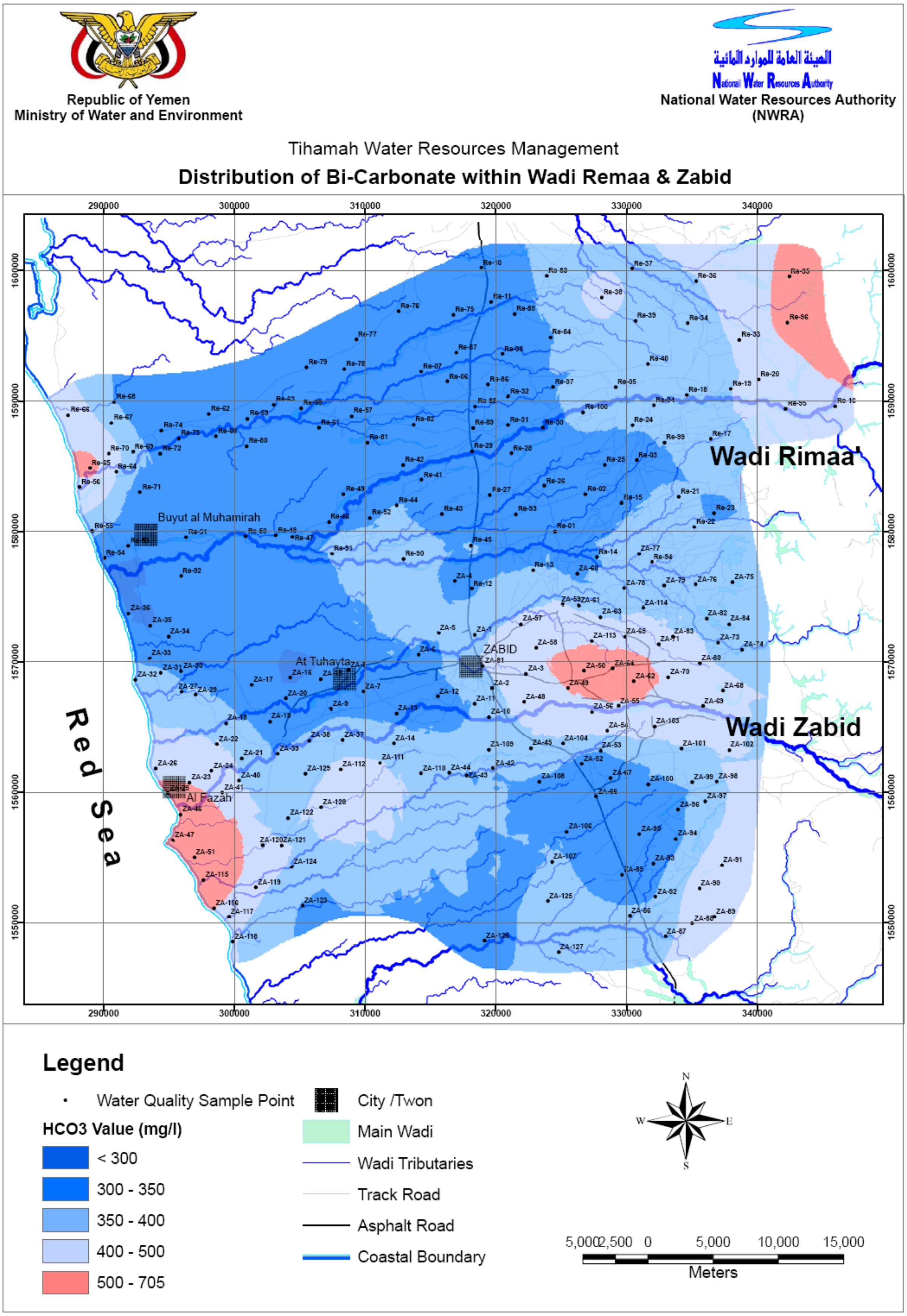


Figure 17: Sulfate Concentration of the study area Samples

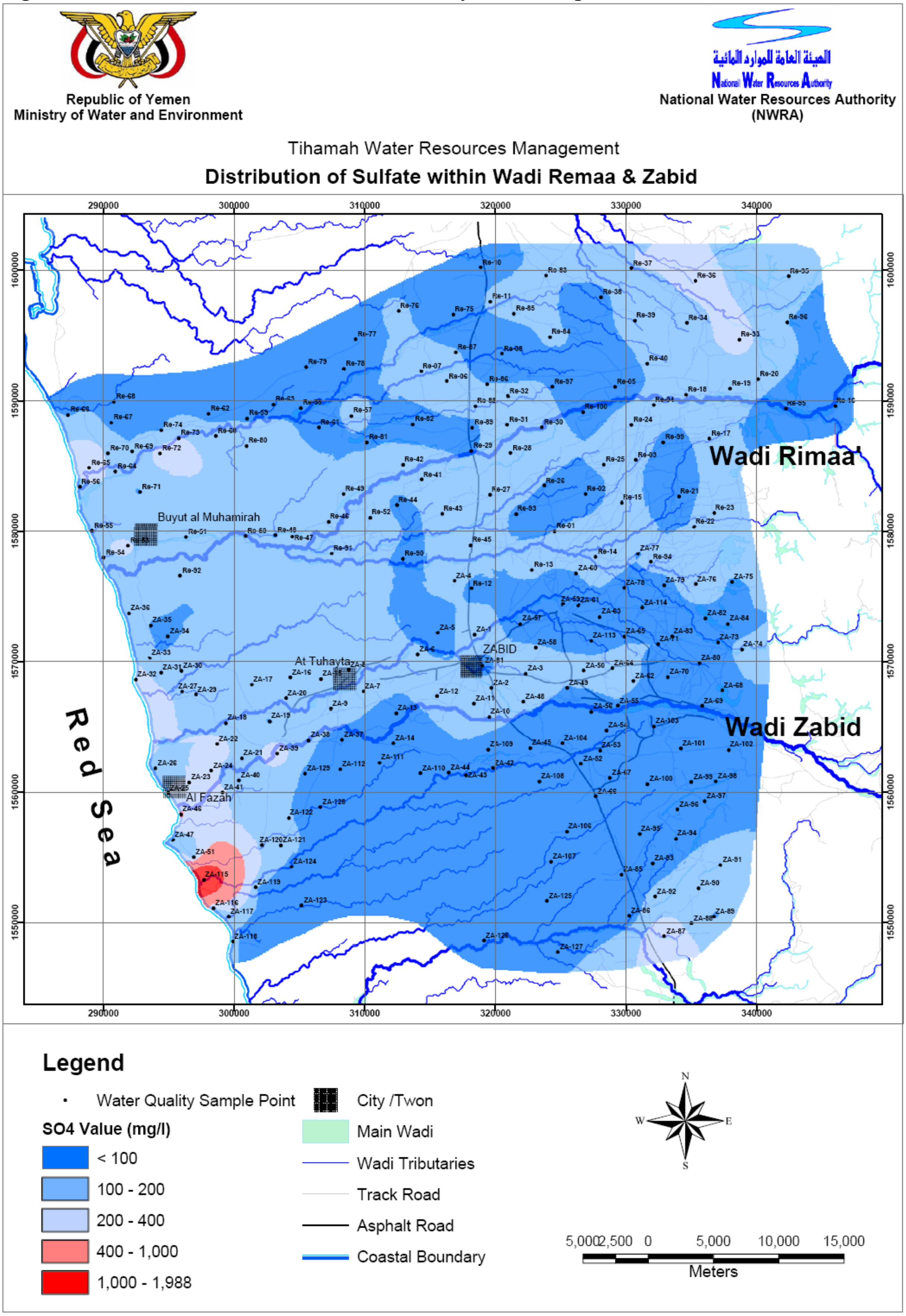
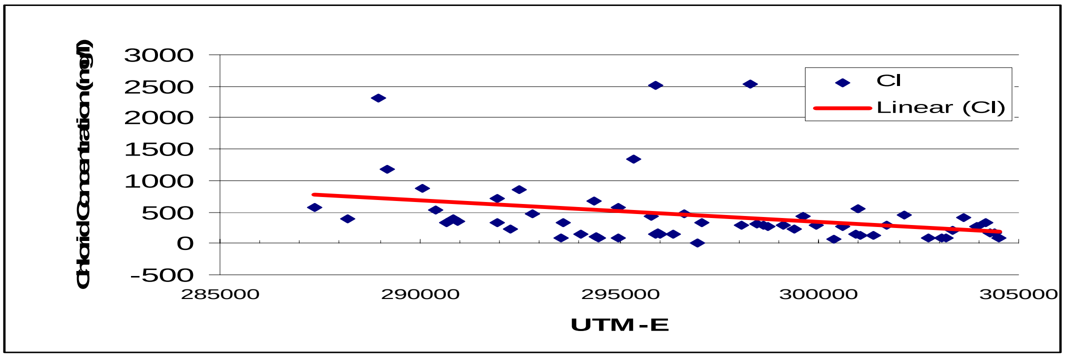


Figure 18 clearly illustrates the general trend of chloride in the study area, rising steadily in the downstream. This trend extends along the entire Wadi from the east to the west. So, this figure implies that the increase in concentration of the chloride may be the result salt water intrusion with fresh water (chloride is the main anion in the sea water). Chloride content ranges between 53 mg/l – 3284 mg/l in Wadi Zabid, while it ranges between 53 mg/l - 2308 mg/l in Wadi Rema'a. Chloride concentration map (Figure 19) shows an increase in chloride contamination in the coastal area.

Figure 18: Increase the chloride concentration in down stream



Nitrate NO3

In the 229 analyzed samples from Wadi Zabid and Wadi Rema'a, nitrate ranges from 1.8 mg/l - 665 mg/l with an average 30 mg/l. Twenty four samples have shown values higher than 50 mg/l (Yemen and WHO Guideline Value) and seventy samples have shown values ranging between 30 – 50 mg/l (therefore coming near risk level). The high amount of nitrates detected (24 samples over 50 mg/l and 70 samples with a 30-50 mg/l) 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 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 20 Shows nitrate distribution in the study area.

Figure 19: Chloride Concentration of the study area Samples

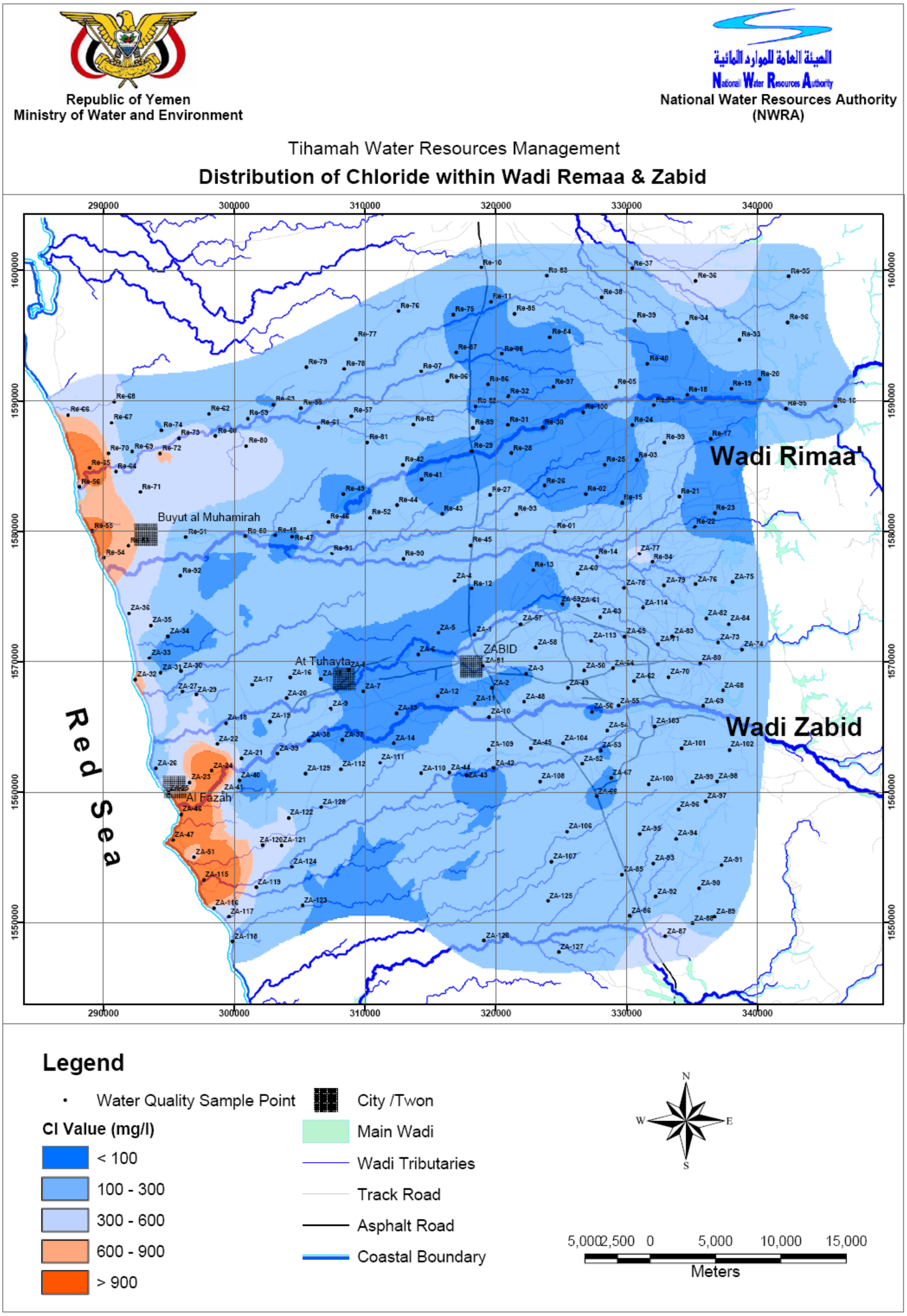
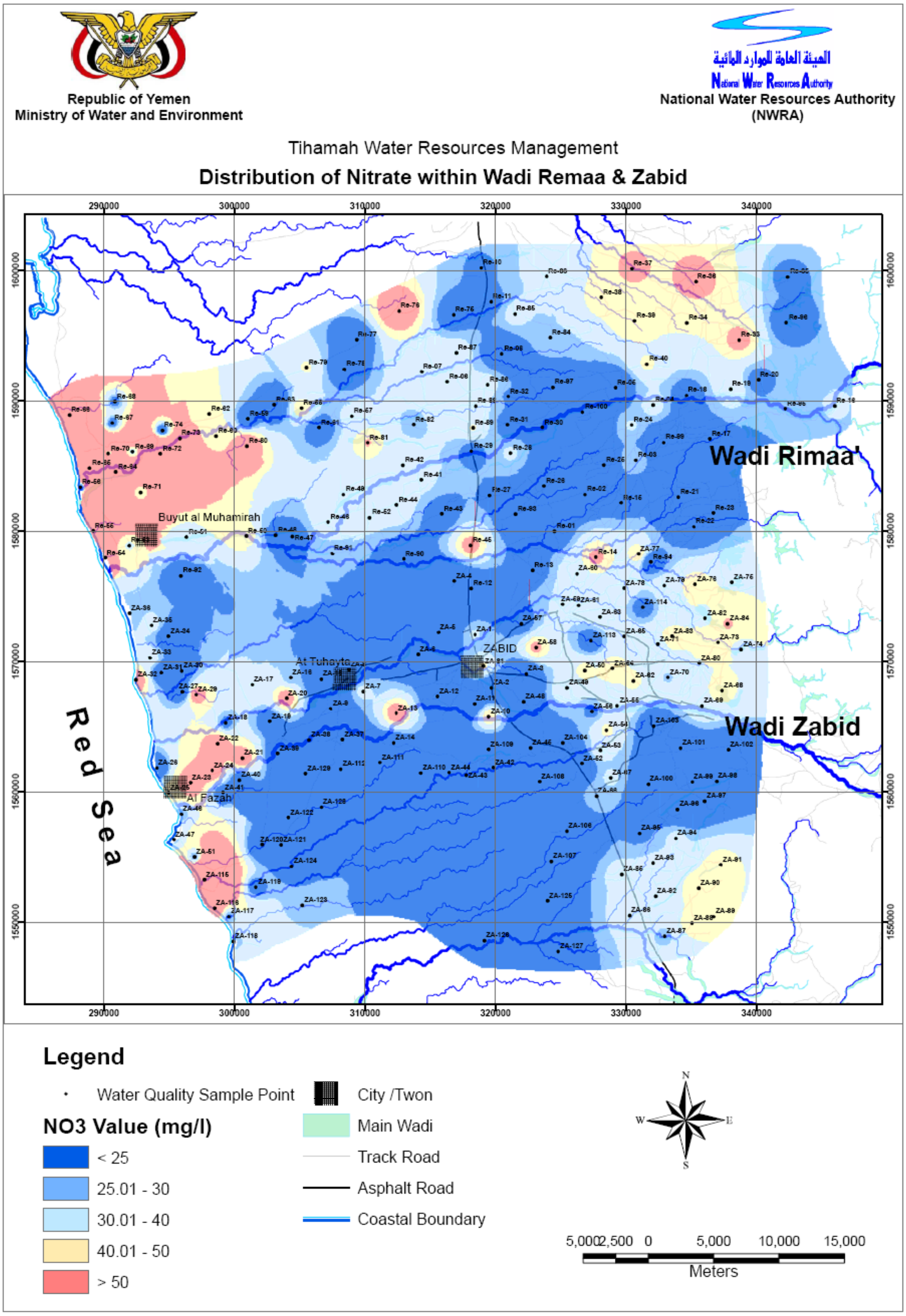


Figure 20: Nitrate Concentration of the study area Samples



Fluoridee (F)

The presence of this element in drinkable water is of the highest importance, as it contributes to protect tooth enamel. Values found range from 0.07 - 1.55 mg/l in Wadi Zabid and from 0.15- 6.175 mg/ l in Wadi Rema'a. There are 9 samples (8 samples in Wadi Rema'a) exceed the Yemeni standard for driking water, but these wells not use for supply water.

Figure 21 clearly illustrates the distribution the fluoridee concentration in the area , which is normal except for a small area in the north west of Wadi Rema'a on the Red Sea .

Total Hardness

Total Hardness is conventionally expressed as total concentration of Ca and Mg (milligrams per litre) 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, values range from 155 - 2262 mg/l in Wadi Zabid and 137 - 1355 mg/l in Wadi Rema'a.

The Hardness concentration map (Figure 22) shows the distribution of the total hardness in the area which increases in the coastal areas and north of Wadi Rema'a.

Figure 21: Fluoride Concentration of the study area Samples

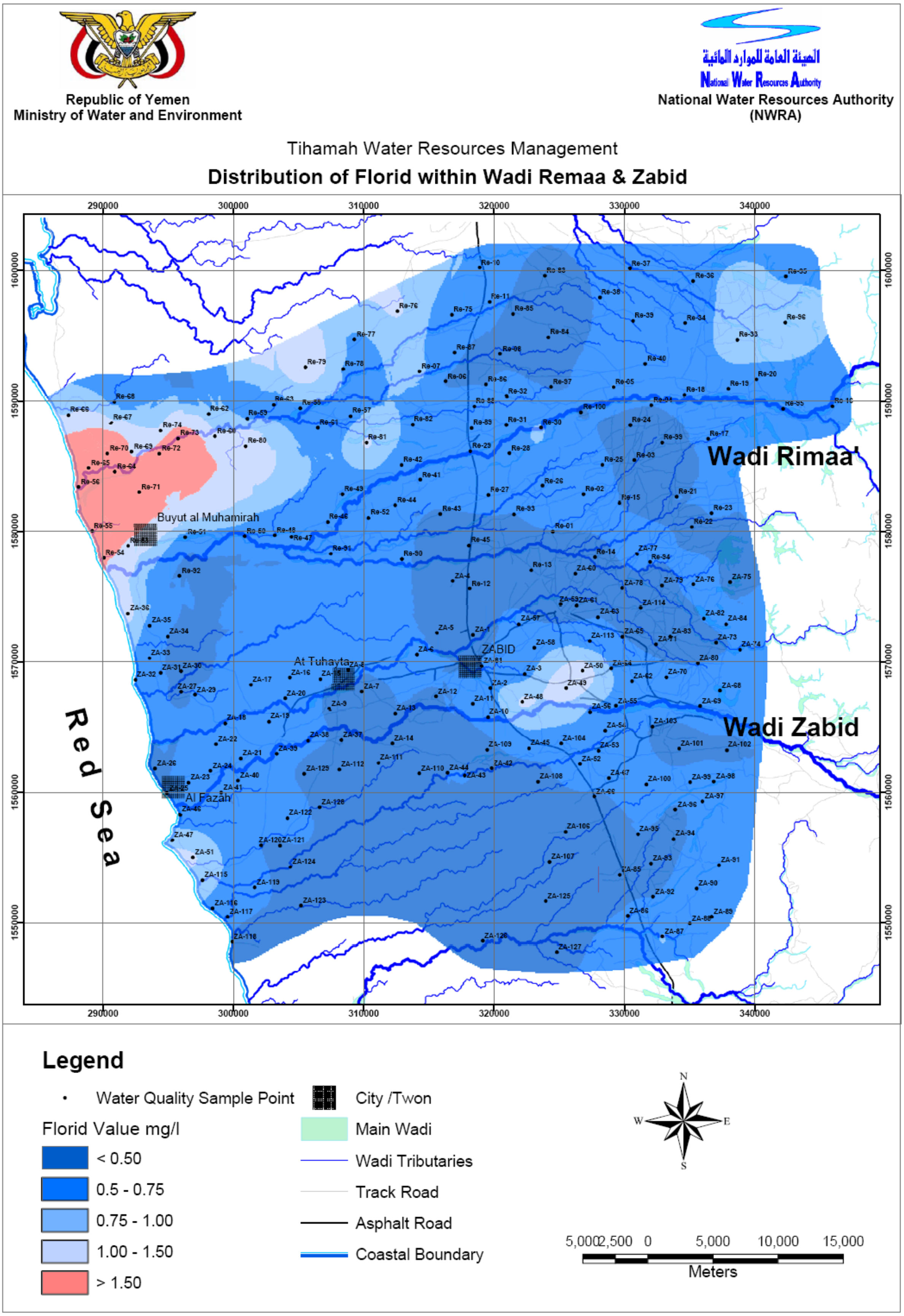
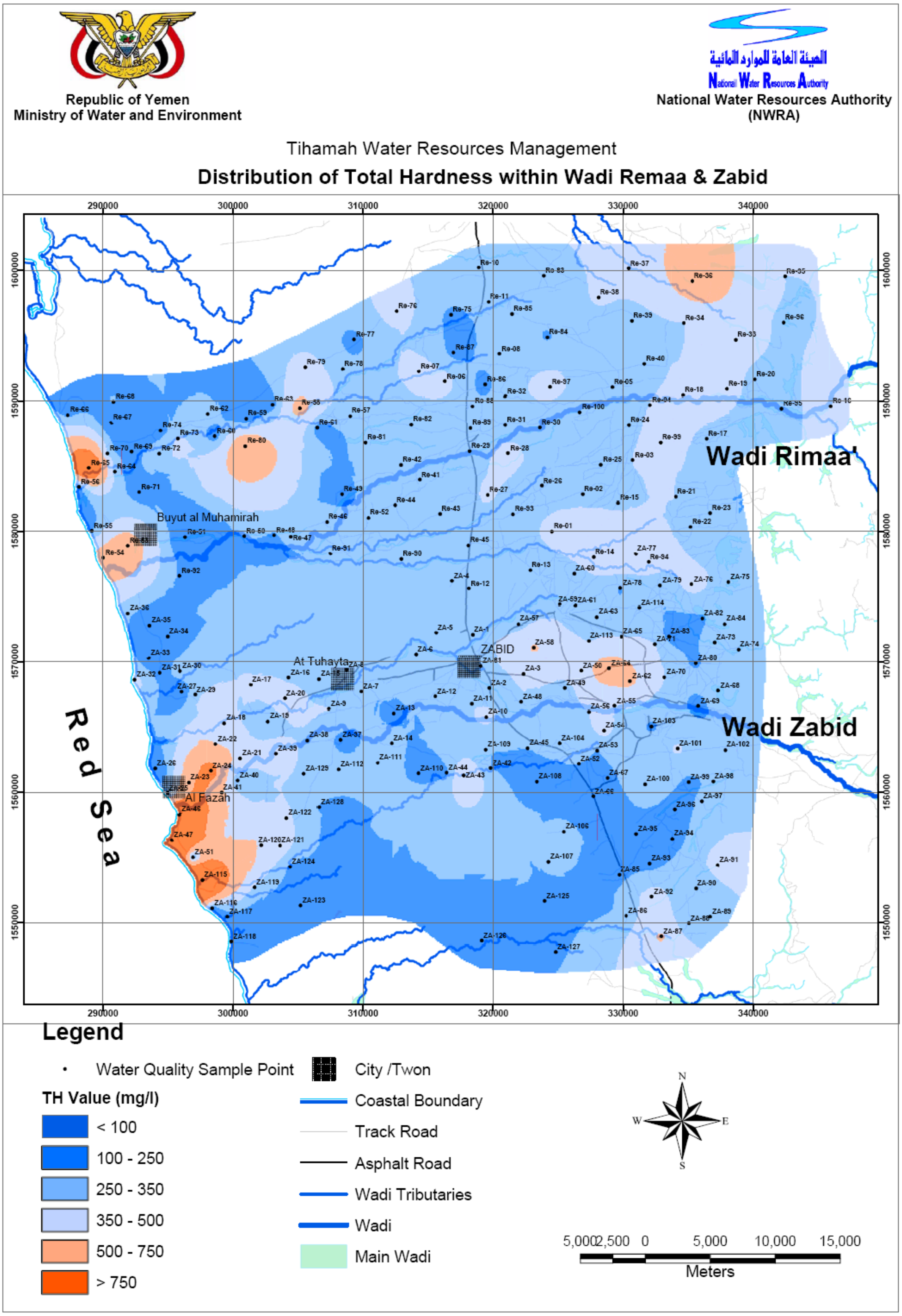


Figure 22: Total Hardness Concentration of the study area Samples



3- Classification of the ground water samples

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 types of water

According to The Piper diagram that was used to identify groundwater chemical water types for 229 samples collected from Wadi Zabid and Wadi Rema'a, 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 Wadis were divided into three parts; upstream including the area more than UTM – E 325000m; mid stream between 325,000m – 305,000m; and down stream less than 305,000m. The Piper diagram has allowed for the identification of three chemical water types, which relate directly to the history and development of the groundwater. Also, the chemical types for the three parts of the Wadis are presented in Table (4) and Figures (23, 24 , 25) and discussed below.

Table 4: Wadi Zabid and Wadi Rema'a Chemical water type

Wadi Name	**No. of Samples**	**Chemical water type**					
		Type 1		**Type 2**		**Type 3**	
		(Ca^{+2} +Mg^{+2}) (HCO_3^-)		**Mix**		**(Na+K)(SO_4+Cl)**	
		no.	**%**	**no.**	**%**	**no.**	**%**
Wadi Zabid	129	15	11.6	101	78.3	13	10.1
Wadi Rema'a	100	10	10	75	75	15	15
Total	**229**	**25**	**10.9**	**176**	**76.9**	**28**	**12.2**

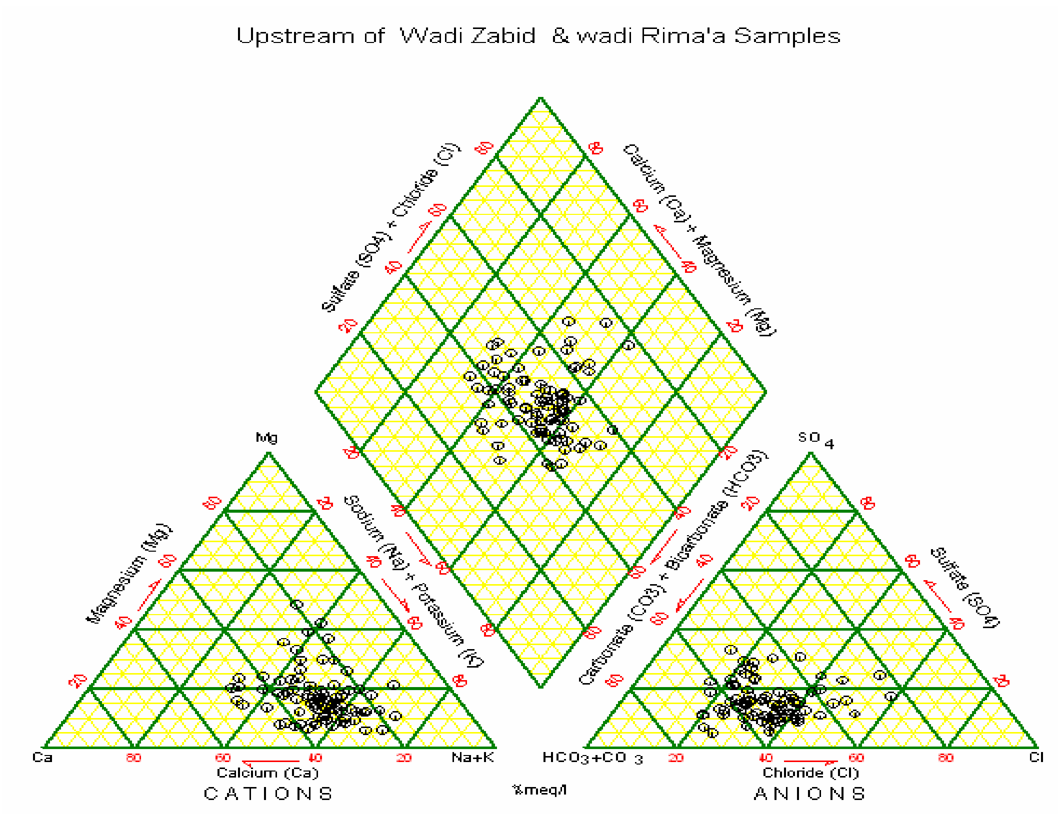
3-1 Wadi Zabid and Wadi Rema'a Chemical water types

3-1-1 Type 1: (Ca+2 +Mg+2) (HCO3 -)chemical water type

The HCO_3 content in groundwater is normally derived from the soil zone CO_2 and the result of the high of rainfall on the mountain as areas (upper catchments area), which the larger available surface runoff, based on observed rainfall patterns and effective catchment area. This groundwater is characterized by domination of the HCO_3^- anion, which is characteristic of recharge areas. Water type 1 represents the major water type in the upstream of Wadi Zabid and Wadi Rema'a.

There are 25 samples of this type and represent about 11% of all samples in the Wadis. These samples are the original type of ground water in the area. Until now the chemical water type for these samples is changing but has not taken on the chemical makeup of type2. Maybe in time this water type change to type 2 resulting from the high pumping and low rainfall on the upper catchment (Figure 23).

Figure 23: The Piper diagram of the Up region stream of the study area



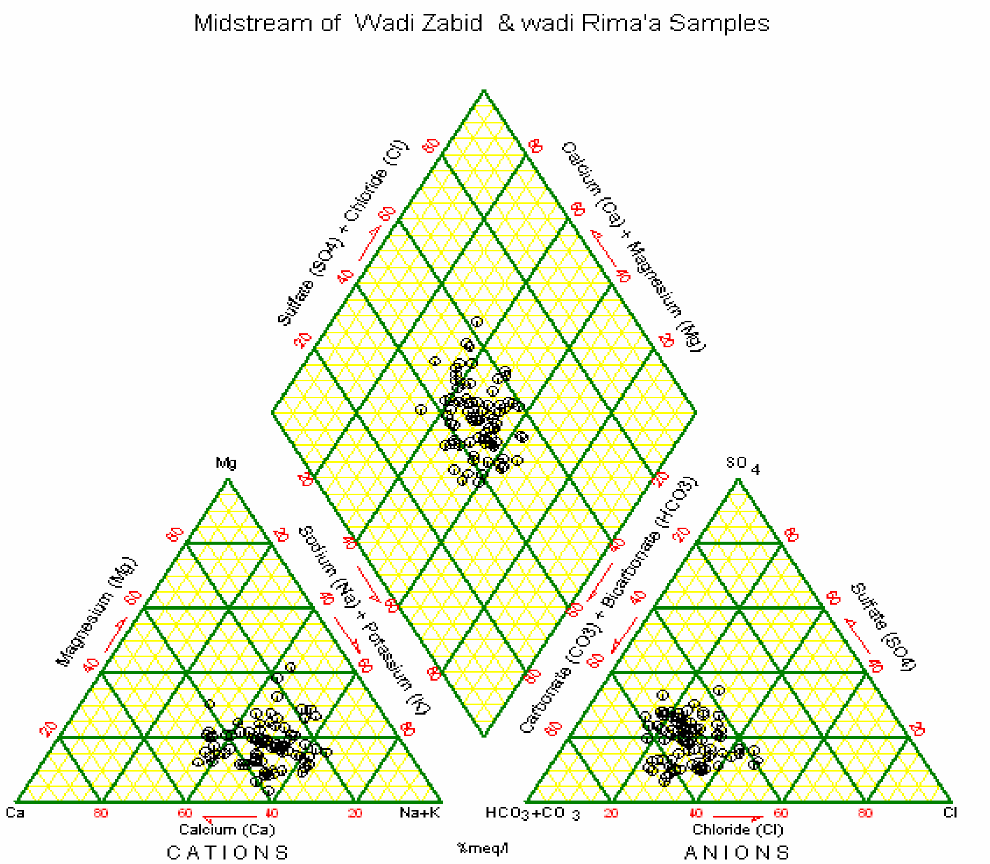
3-1- 2 Type 2: Indiscriminate Ions (Mixed) Waters

This groundwater type appears to represent a hydrochemical evolution of Type 1 water, or mixing of the recently recharged type 1 waters with the more saline waters from the intrusion of sea water to fresh water zones.

The chemical evolution from water type 1 to water type 2 can be traced through samples in which the dominancy of HCO_3^- reduces. Type 2 appears to evolve due to enrichment of other anions such as SO_4 or Cl, as it passes through the source(s) of these ions. As the water type evolves, this type may be evolution to type 3 due to enrichment of Na^+ cations instead of other Ca^{+2} and Mg^{+2} cations resulting from the intrusion of saline water to fresh water.

Until now this water type concentrated in the midstream region (about 77% of samples which collected from Wadi Zabid & Rema'a). However it will probably encroach to the upstream region because of the intense pumping of groundwater in the Wadis and the low rainfall on the upper catchments. See Figure (24).

Figure 24: The Piper diagram of the midstream of the study area



3-1-3 TYPE 3: (Na+K)(SO_4+Cl)

This type is rich in Na cations and Cl anions, and is mainly present in the coastal area. This water type represents a hydrochemical evolution of Type 2 water (mixing of the Type 2 waters with the more saline waters which intrusion to type 2 water [mixing water] with sea water). There are about 25 samples (11%) of this type and it represents the major water type in the down stream region in the coastal area. This area is effected by the sea water intrusion to the groundwater. Figure 25 shows the distribution of the samples in the downstream region and Figure 26 shows the increase in the average values of Na & Cl in the downstream side.

Figure 25: The Piper diagram of the down stream of the study area

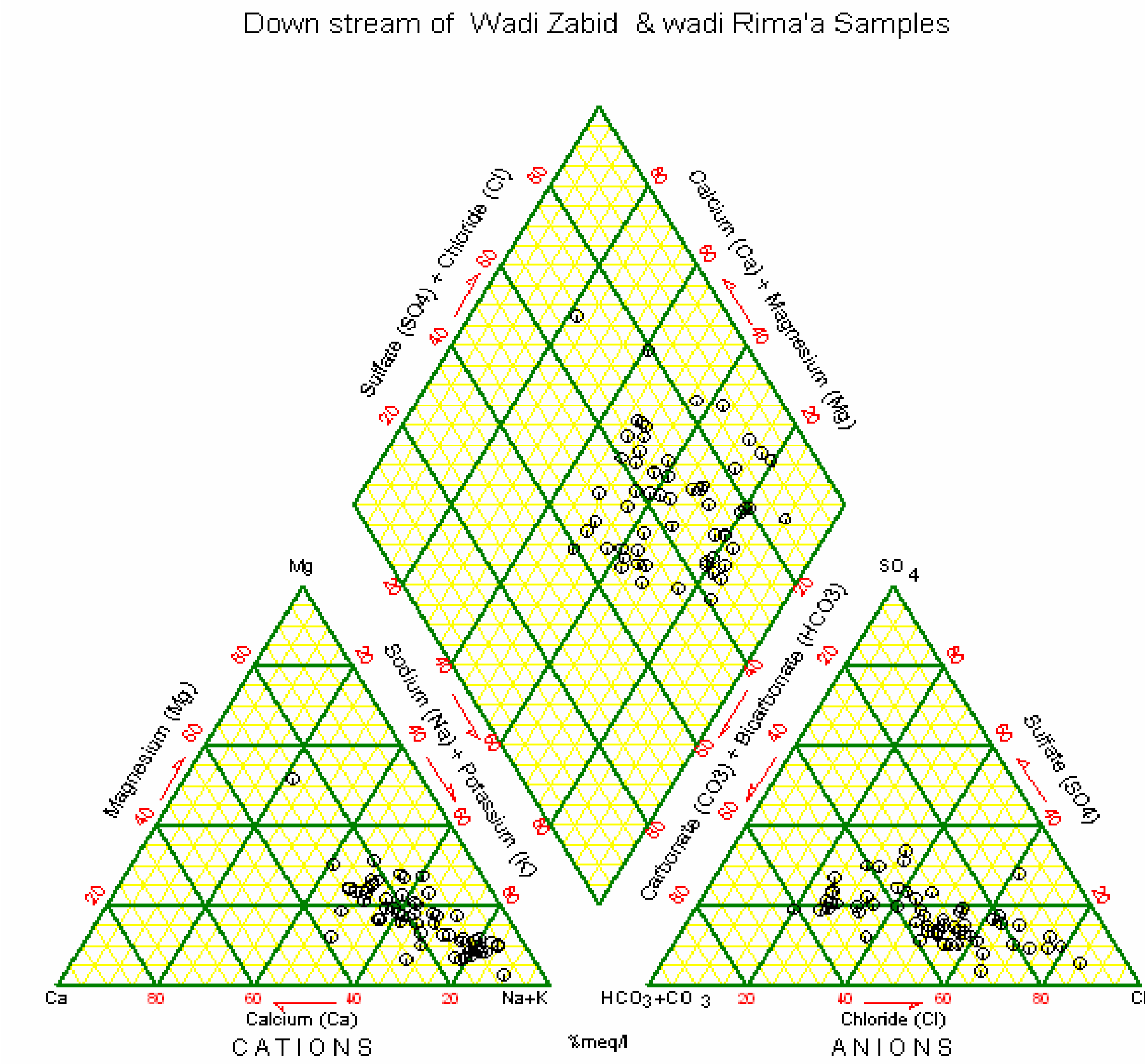
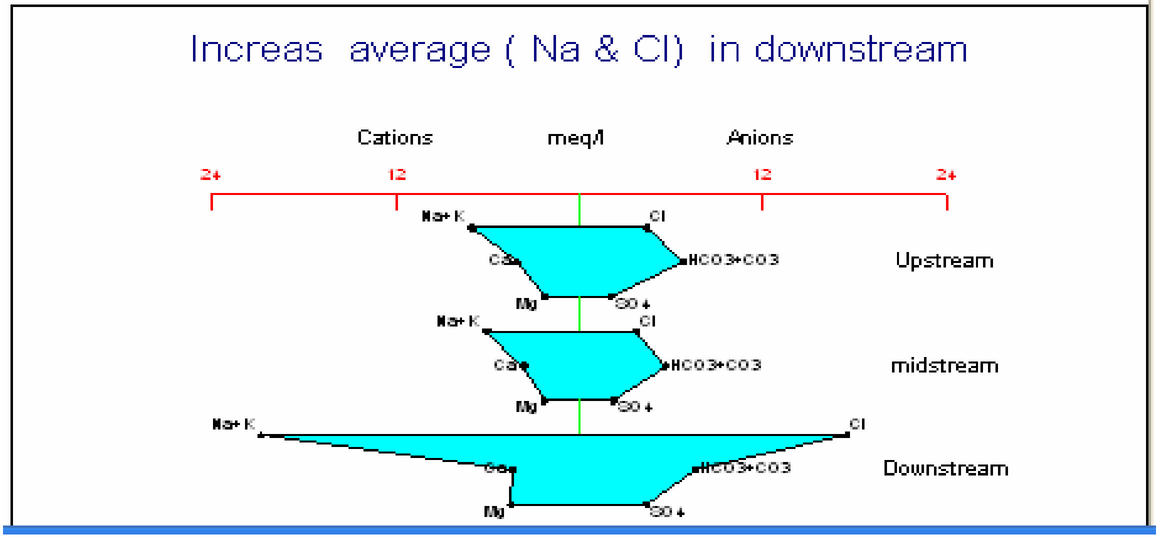


Figure 26: Increase of Na & Cl in the down stream region of the study area



3-2 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 27.

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

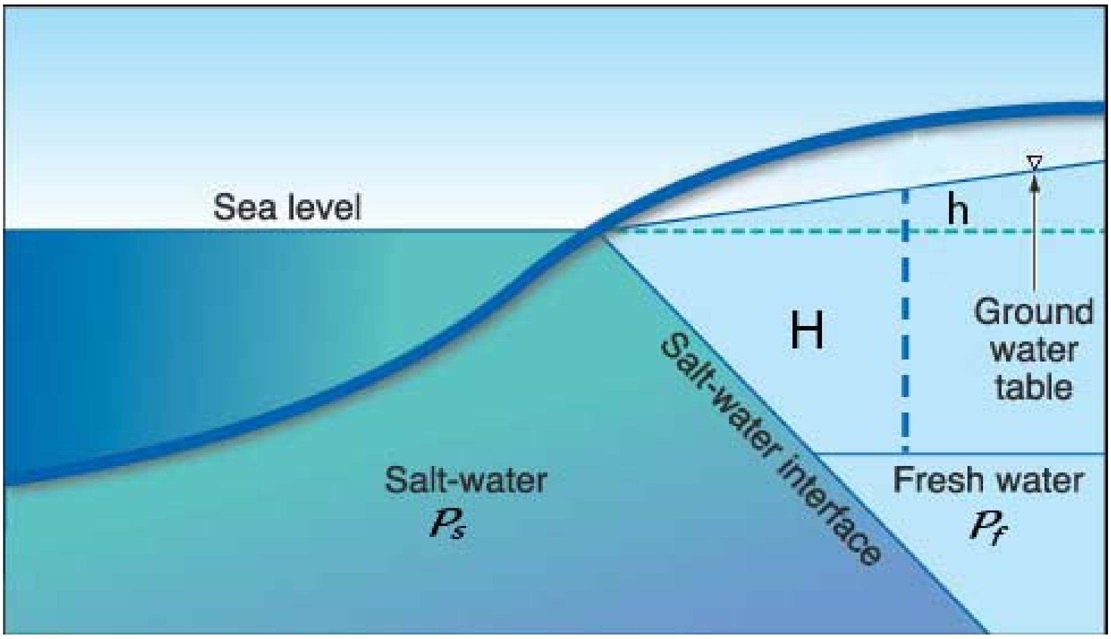


Figure 27: Salt water Intrusion phenomena

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 The studu area, especially in Butut Al Muhaimirah, Ma'abar Al Gah, Ashwatebah and Assafariah in Wadi Rema'a and Al Fazah, Al Matinah and Al Noktah in Wadi Zabid 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.

* * *

4- Water quality evaluation

Water quality refers to the water chemical, biological and physical characteristics. The use of water (drinking, irrigation …etc.) is the main factor in determining the required water quality. Water is said to be good or acceptable for a special use, if its characteristics meet the standards for that use. A standard is the concentration of the constituent that does not result in significant risks (negative impact) to the health of the consumer or consuming system over the lifetime of consumption. Short-term deviations above the standard values do not necessarily mean that the water is unusable for consumption. The amount by which and the period for which any standard value can be exceeded without affecting public health depends upon the specific substance involved.

In total, 229 water samples were analyzed throughout Wadi Zabid and Wadi Rema'a as 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.

4-1- Evaluation of water for Drinking (Domestic)

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 50 of the wells sampled being from water supply 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 is given in Table (5).

It should be noted that very few samples were found to be over the Maximum Permissible Limit (MPL), and more than 80% of the samples had levels between Optimal Limits and Maximum Permissible Limit.

With respect to Nitrate element, only 12 % of samples (28 sample) were found over Maximum Permissible Limit (MPL). These samples were dug wells and concentrated in the west / north of the study area. Also regarding Chloride, about 4% of samples (10 samples) were found over Maximum Permissible Limit (MPL). These samples were from wells are concentrated in the west of the study area on the coast and may be affected by salt water intrusion.

Table 5:Suitability of water samples for drinking water in the study area

Element	Optimal Limits (mg/l)	Samples within (OL)	Maximum Permissible Limit(mg/l)	Samples within (MPL)	Samples over the (MPL)
TDS	650	43	1500	167	19
Calcium	75	131	200	94	4
Magnesium	30	155	150	70	4
Sodium	200	177	400	40	12
Potassium	8	217	12	4	8
Bicarbonate	150	0	500	214	15
Chloride	200	173	600	46	10
Sulfate	200	213	400	13	3
Nitrate	10	39	50	162	28
Iron	0.3	37	1	177	15
Flouride	0.5	100	1.5	120	9
Total Hardness	100	209	500	20	0

According to the field information of sampled wells, only 50 wells are in use for supply. Only 14 wells are borehole wells. The remaining wells are dug and dug/bore well. Results of drinking-water quality classification for samples collected from these supply wells are given in Table 6.

It should be pointed out that 80% of the supply wells (40 wells) are classified as suitable for drinking water, and only 20 % of the supply wells (10 wells) exceed the Yemeni standard for drinking water in some elements. 4 samples had levels higher than the MPL with respect to Nitrate. These samples are found in Wadi Rema'a and taken from dug and dug/bore wells. The water levels for these wells are near the surface, so they exhibited signs of pollution from sewage, especially all the wells sourced by the alluvium deposit. Table 7 shows these samples and their location

Table 6: Water suitability for supply projects water samples

Element	Optimal Limits (mg/l)	Samples within (OL)	Maximum Permissible Limit(mg/l)	Samples within (MPL)	Samples over the (MPL)	Sample No. Over the (MPL)
TDS	650	15	1500	34	1	Re-36
Calcium	75	24	200	26		
Magnesium	30	38	150	12		
Sodium	200	48	400	2		
Potassium	8	50	12			
Bicarbonate	150		500	49	1	Re-38
Chloride	200	46	600	4		
Sulfate	200	49	400	1		
Nitrate	10	8	50	38	4	Re-14, Re-36, Re-37, Re-76
Iron	0.3	10	1	39	1	Za-34
Flouride	0.5	26	1.5	24		
Total Hardness	100		500	47	3	Re-14,Re- 16, Re-36

Table 7: The supply wells which exceed Yemeni Standard for drinking water

Well No	Site	well type	Location		N0. of exceed elements	Exceed Element Type
			UTM East	UTM North		
Za-34	Attafaf	Bore	294973	1571921	1	Fe
Re-14	Al Baratah	Dug/Bore	327725	1578004	2	NO_3, TH
Re-16	Meshrafah	Dug/Bore	345975	1589585	1	TH
Re-76	Al Mahabib	Dug/Bore	312589	1596894	1	NO_3
Re-38	Al Mabkariah	Dug	328104	1597932	1	HCO_3
Re-36	Al Gumaeiah	Dug	335310	1599147	3	TDS,NO_3, TH
Re-37	Al Mationiah	Dug	330420	1600120	1	NO_3

4-2- 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.

4-2-1 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 8.

Table 8: 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	0	Sensitive plants may show stress; moderate leaching prevents salt accumulation in soil.
C3	750 - 2250	209	Salinity will adversely affect most plants; requires selection of salt-tolerant plants, careful irrigation, good drainage, and leaching.
C4	> 2250	20	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 classified as C3 water type (209 samples) with EC values between 750- 2250 (µS/cm), while 20 sample were classified as C4 with EC > 2250 µS/cm). These classifications refer to water that is unacceptable for irrigation, except on very salt tolerant plants with field conditions including excellent drainage, frequent leaching, and intensive management.

4-2-2 Sodium hazard

The main problem with high sodium concentration is its effect on soil permeability and water infiltration. Sodium also contributes directly to the total salinity of the water and may be toxic to sensitive crops. The sodium hazard of irrigation water is estimated by the sodium absorption ratio (SAR), which is calculated by the following formula:

$$SAR = Na^{+} \div \sqrt{0.5(Ca^{+2} + Mg^{+2})}$$

The cations are expressed in meq/L.

Continued use of water with a high SAR leads to a breakdown in the physical structure of the soil. The sodium replaces calcium and magnesium absorbed by the clay minerals and causes dispersion of soil particles. This dispersion results in breakdown of soil aggregates and causes a cementation of the soil under drying conditions as well as preventing infiltration of rain water. Classification of irrigation water based on SAR values is shown in Table (9).

Table 9: Classification of irrigation water based on SAR values

Level	**SAR**	**No of samples**	**Hazard**
S1	<10	211	No harmful effects from sodium
S2	10-18	13	An appreciable sodium hazard in fine-textured soils of high EC, but could be used on sandy soils with good permeability
S3	18-26	4	Harmful effects could be anticipated in most soils and amendments such as gypsum would be necessary to exchange sodium ions.
S4	>26	1	Generally unsatisfactory for irrigation.

Most the samples collected during this study belong to the S1 group with SAR values of< 10, except 13 samples which belong to the S2 group with SAR between 18- 26, while 5 samples belong to the S3 and S4 groups with SAR values of > 18 which it is near the coastal line.
The quality classification of irrigation water, based on conflation the salinity (EC) values and SAR value is given in Table (10).

Table 10: Classification of irrigation water based on SAR

Number of Samples in class		**Salinity Hazard**			
		Very High	High	Medium	Low
Sodium Hazard		>2250 (µS/cm)	750-2250 (µS/cm)	250-750 (µS/cm)	<250 (µS/cm)
Very High	>26	1	None	None	None
High	18-26	4	None	None	None
Medium	10-18	6	7	None	None
Low	<10	9	202	None	None
Total		20	209	None	None

Bases on the above table, 5 sample with very high salinity and very high sodium hazard. The quality of the water is very poor and not suitable for irrigation (Re- 65,55 in Wadi Rema'a and Za-25,24 and 115 in Wadi Zabid).
15 samples had very high salinity and medium and low in sodium hazard, meaning the water is poorly for irrigation. 7 samples had high salinity and medium sodium hazard, indicating marginal water quality. 211 samples were admissible for irrigation .

4-2-3 Soluble sodium percentage

Soluble sodium percentage (SSP) is an estimation of the sodium hazard of irrigation water like SAR, but it expresses the percentage of sodium out of the total cations and not as SAR correlating the sodium with the Ca and Mg only. SSP is calculated by the following formula:

$$\mathbf{SSP = ((Na^{+} + K^{+}) / (Ca^{2+} + Mg^{2+} + Na^{+} + K^{+})) * 100}$$

The ionic concentrations are in meq/L.

Based on the Todd (1980) classification for irrigation water according to the soluble sodium percentage (Table 11), it was found that 26 samples had SSP values between 20 and 40 indicating good water classification. 145 samples had SSP 40- 60 indicating permissible water classification. 50 samples had SSP values between 60 and 80 indicating doubtful water classification. 8 sample had SSP > 80 indicating the water is unsuitable water for irrigation. These wells are: (well no. Re- 55,66,67,71,72 in Wadi Rema'a and Za-25,51 and 116 in Wadi Zabid).

Table 11: Classification of irrigation water based on the SSP

Water Class	**SSP**	**EC µs/cm**	**No of Samples**
Excellent	< 20	> 250	None
Good	20-40	250-750	*26
Permissible	40-60	750-2000	145
Doubtful	60-80	2000-3000	50
Unsuitable	> 80	> 3000	8

* these sample with SSP 20- 40 and EC more than 750 **µs/cm**

4-3- Hydrochemical Criteria for Industrial

The quality requirements of water used in different industrial process vary widely. Thus, the criteria for nutrient industrial water must be good quality while water of low quality such as brackish water can be satisfactorily employed for the cooling.

There are three parameters that usually are important for industrial water criteria, include the salinity, hardness, and silica.

In Wadi Zabid and Wadi Rama'a there are many small factories. Some of these factories such as tanneries and block factories do not need high quality water, while others like purification plant, ice cream producers and date palm cleaners are need to good quality water.

So, an adequate groundwater supply of suitable quality water often becomes a primary consideration in selecting a new industrial plant type and location.

5. Vulnerability Assessment of Wadi Zabid &Wadi Rema'a

5.1 General

The vulnerability of the groundwater reservoir is limited to main valley and larger tributaries.

The reason for the vulnerability is due to the excessive pumping resulting lowering the piezometric surface, mismanagement, contamination from saline groundwater, point sources (e.g. spills, cesspits and waste disposal, leakage from storage tanks at petrol filling stations, factories and waste water) and diffuse sources, including irrigation return water containing pesticides and fertilizers.

5-2 System description:

The alluvial aquifer is limited to the main valley of Wadi Zabid and Wadi Rema'a and the larger tributaries, an area of approximately 2242 km2 in the study area. The unconsolidated alluvium consists of clay, sand, gravel and silt up to 300 m thick. Natural recharge is limited to infiltration of infrequent surface flows in the upper part of the catchement in the east of the study area. Recharge also occurs from the return of irrigation water and losses from the piped distribution system in the towns and cess pits. Historically, the valley was a zone of groundwater discharge with baseflow and evaporative losses in parts of the main channel. The background water quality is variable, with good quality water with a typical conductivity of < 1000 µS/cm in the up and midstream. The groundwater is of poor quality and brackish-saline in the down stream of > 12000 µS/cm with average 1500µS/cm .

Increased abstraction of groundwater for agricultural and domestic use has caused the lowering of heads in the valley, particularly in the mid stream (mid valley).

This resulted in the expansion of natural, saline water, combined with input of salts from irrigation return and waste water.

The aquifer is most vulnerable to deterioration in water quality as abstraction increases. This appears to be mainly due to the spreading of pre-existing saline water, leaching of salts in the unsaturated zone by irrigation waters, and solution / mobilisation of salts in the subsurface strata along with some surface contamination.

Using the UK Environment Agency's vulnerability classification (National Rivers Authority, 1992), the entire alluvial aquifer would be classified as a minor aquifer with high to intermediate vulnerability. This classification arises because the aquifer is unconsolidated and of limited extent and overlain by soils which can transmit contaminants but are not highly permeable.

5-3 Vulnerability assessment using parametric methods

Rapid vulnerability assessment using the GOD empirical system was assessed as follows:

1. **G**roundwater occurrence - unconfined, rating = 1.0
2. **O**verall aquifer class, alluvium, rating = 0.7
3. **D**epth to groundwater table, 10-20m, rating = 0.7

Output Aquifer Pollution vulnerability = 0.5 (moderate to high)

The geology of Wadi Zabid and Wadi Rema'a is compassed mainly of unconsolidated alluvium consists of clay, sand and gravel.

The depth to water level in the region differs from one area to another, and according to the differences in the depth of the water, the vulnerability can be divided into three Types:

Type 1: Alluvial deposit with shallow water level <20 m

This type is concentrated in the down stream region by the coast and in eastern area near the upper catchment with an average depth of 8.5 m and according to the equation:

1. Groundwater occurrence - unconfined, rating = 1.0
2. Overall aquifer class, alluvium, rating = 0.7
3. Depth to groundwater table, 10-20m, rating = 0.7

Output Aquifer Pollution vulnerability 0.5, moderate to high (Red color).

Type 2: Alluvial deposit with medium water level between 20-50 m

This type is concentrated in the mid and down stream region with an average depth of 33 m and according to the equation:

1. Groundwater occurrence - unconfined, rating = 1.0
2. Overall aquifer class, alluvium, rating = 0.7
3. Depth to groundwater table, 20- 50m, rating = 0.6

Output Aquifer Pollution vulnerability 0.42, moderate (Yellow color).

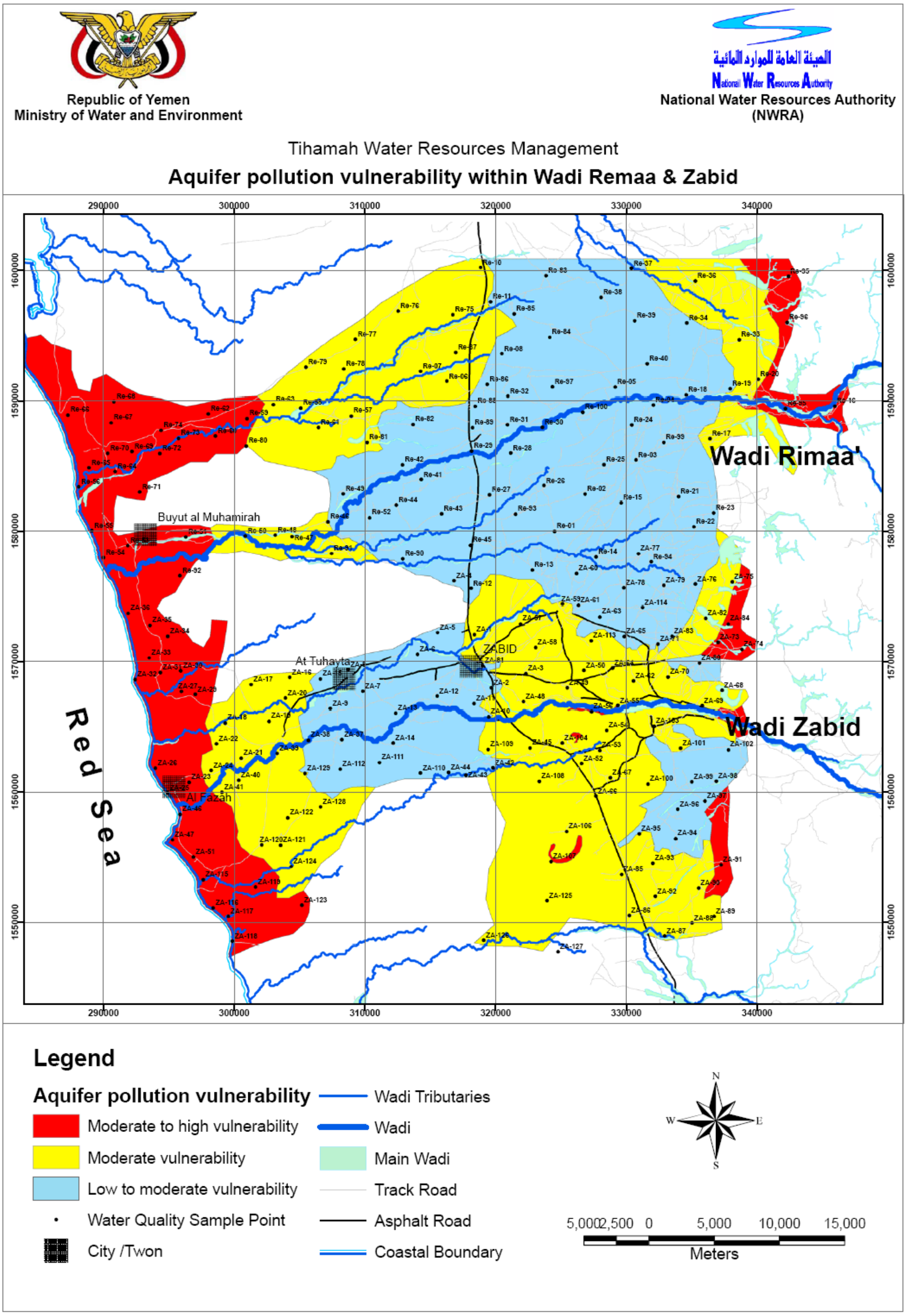
Type 3: Alluvial deposit with deaper water level >50 m

This type is concentrated mainly in the mid stream region with a small part to the east ant south of the upstream region with an average depth of 65 m and according to the equation:

1. Groundwater occurrence - unconfined, rating = 1.0
2. Overall aquifer class, alluvium, rating = 0.7
3. Depth to groundwater table, >50 m, rating = 0.5

Output Aquifer Pollution vulnerability 0.35, low to moderate (blue color).

Figure 28: Aquifer pollution vulnerability of the study area samples



6- Conclusion and Recommendation

- From the 12339 wells inventoried in Wadi Zabid and Wadi Rema'a during 2005-2006 well inventory, 229 water samples were collected from dug and drilled wells during November 21, 2007 – January 2, 2008 in order to study the water quality and examine the vulnerability and exposure of the water resources to pollution
- The water samples were analyzed in the Tihamah Development Authority Laboratory and the major anionas and cations were measured; then the results were checked by three different methods which indicated that the results were tallying and are correct
- Results of the analyses indicated three types of chemical water types in the study area {$(Ca^{+2} + Mg^{+2})(HCO_3^{-})$, $(Na+K)(SO_4+Cl)$} and a mix of the two types. These types of water were concentrated in the upstream, down stream and midstream respectively. This means that the groundwater salinity is low in the upstream and increases in the direction of the down stream and becomes very high near the coast
- According to the evaluation of the water samples, about 80% of the supply wells are classified as suitable for drinking water, and only 20 % of these wells exceed the Yemeni standard for drinking water in some elements
- Only 5 water samples were unsuitable for irrigation because of very high salinity and very high sodium hazard, while 15 water samples were evaluated as poor for irrigation
- The aquifer pollution vulnerability study depended on the depth of the groundwater because the geology of Wadi Zabid and Wadi Rema'a is compassed mainly of unconsolidated alluvium consisting of clay, sand and gravel. So the vulnerability in the central area was low to moderate (the average depth to water level is > 50 m) and increase in the western and eastern parts and becomes high in the coast and near the upper catchment

- The source of drinking water for some wells in Wadi Rema'a especially in Al Baratah, Al Gumaeiah, Al Mationiah and Al Mahabib villages should be change because it were have high concentration of nitrate
- we recommend to collect water samples from supply and domestic wells in the wadis and conduct a biological analysis because if a high concentration of nitrate was found we could determine the source of nitrate pollution
- we recommend to make a water quality network to monitoring the increase of salinity in the coastal regions and the increase of nitrate of the some villages.

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Annex II : Water-points sampled, analyzed in the study area

Sample No.	Well No.	Site	Well Type	UTM East	UTM North	Total Depth (m)	Water Use
ZA-001	F-0002	Zabid	Bore	318411	1572050	75	Domastic
ZA-002	C-1268	Zabid	Bore	319726	1567955		Irrigation
ZA-003	F-0251	Al Quraiah	Dug/Bore	322357	1569054	50	Animals
ZA-004	C-0987	Al Qurashiah	Bore	316859	1576166	150	Irrigation
ZA-005	C-0994	Al Sottor	Bore	315606	1572218	100	Irrigation
ZA-006	C-1001	Al Muga'ar	Dug/Bore	314068	1570560	150	Irrigation
ZA-007	C-1376	Al Tuhaita	Dug/Bore	309889	1567683	144	Irrigation
ZA-008	C-1438	At Twhaita	Bore	308771	1569364		Supply
ZA-009	C-1423	Al Ryamiah	Dug	307405	1566381	75	Supply
ZA-010	C-1246	Torquah	Dug	319516	1565760	66	Irrigation
ZA-011	C-1239	Botailah	Dug	318380	1566744	75	Irrigation
ZA-012	C-1162	Mahwa Al Khalif (Al Tohayta)	Bore	315569	1567319	137	Supply
ZA-013	C-1095	Al Mosallab (Al Tohayt	Dug/Bore	312405	1566027	130	Irrigation
ZA-014	C-1834	Al Owain (Al Tuhayta)	Dug/Bore	312206	1563743		Irrigation
ZA-015	C-1488	Al Nasery Al Asfal	Dug/Bore	306645	1568657	72	Irrigation
ZA-016	C-1500	Al Nasery Al Asfal	Dug	304309	1568772	60	Irrigation
ZA-017	E-1666	Al Nasery Al Asfal	Dug/Bore	301346	1568210	90	Irrigation
ZA-018	D-1472	Al Nasery Al Asfal	Dug/Bore	299373	1565284	60	Irrigation
ZA-019	D-1719	Al Nasery Al Asfal	Dug/Bore	302719	1565413	60	Irrigation
ZA-020	C-1508	Al Nasery Al Asfal	Dug/Bore	303964	1567178	56	Irrigation
ZA-021	D-1511	Al Mudaman	Dug/Bore	300595	1562590	80	Irrigation
ZA-022	D-1478	Al nasery Alasfal(Al tuhaita)	Dug	298697	1563676	33	Irrigation
ZA-023	D-1438	Bany Shnainy(Al tuhaita)	Dug	296602	1560713		Domastic
ZA-024	D-1448		Dug	298289	1561632	35	Irrigation
ZA-025	D-0954	Al Fazah	Dug	294950	1559898	15	Mosqu
ZA-026	D-0905	Al Mojailis	Dug	294032	1561812	8	Domastic
ZA-027	E-1446A	Al Garobah Village	Bore	296012	1567672	50	Supply
ZA-029	E-0764	Al Nasery Al Asfal	Dug	297074	1567442	23	Domastic
ZA-030	E-1419	Al Mojailis	Dug	295978	1569270	15	Irrigation
ZA-031	E-1681	Al Habshah- Al Mojailis	Dug	294409	1569143		Domastic
ZA-032	E-0785	Al Noktah	Dug	292472	1568603		Domastic
ZA-033	E-1199	Wadi Al Mojailis	Dug/Bore	293554	1570273	10	Irrigation
ZA-034	E-0854	Attafaf	Bore	294973	1571921	60	Supply
ZA-035	E-0881	Al Te'afaf	Dug	293622	1572779	14	Domastic
ZA-036	E-0952	Wadi Al Mojailis	Dug	291948	1573702		CLEANING
ZA-037	C-1625	Al Maghras(Al Tohayta)	Bore	308295	1563991	150	Supply
ZA-038	C-1543	Dawm Al Hady (Al Tuhayta)	Bore	305740	1563957	120	Supply
ZA-039	D-1658	Al swaiq(Al Tohayta)	Dug/Bore	303331	1562943		Domastic
ZA-040	D-1607	Al fourse (Al Tohayta)	Bore	300395	1560886	95	Supply

Sample No.	Well No.	Site	Well Type	UTM East	UTM North	Total Depth (m)	Water Use
ZA-041	D-1588	Al faeg (Al tuhaita)	Dug	299120	1559929	19	Domastic
ZA-042	G-0455		Dug	319829	1561835	65	Domastic
ZA-043	G-0441	Al Shobaita'a (Al Jarahy)	Bore	317769	1561267	130	Domastic
ZA-044	G-0442	Kodf Al Romah (Al Jarahy)	Bore	316453	1561468	130	Domastic
ZA-045	G-0207	Al Torbah (Al Jarahy)	Dug	322679	1563366	40	Domastic
ZA-046	D-1387	Dom Al qaaieb (Al)	Dug	295921	1558267	5	Domastic
ZA-047	D-0960	Al Fazah	Dug	295334	1556324	3	Domastic
ZA-048	F-0643	Al bajhah (Zabid)	Dug	322171	1566896	40	Irrigation
ZA-049	F-0749	Al zareebah(Zabid)	Dug/Bore	325508	1567956		Domastic
ZA-050	E-1914	Mahwa Al Atter (Zabid)	Dug	326781	1569299		Irrigation
ZA-051	D-0974	Al Mothainah	Dug	296933	1555012	10	Domastic
ZA-052	G-0586	Al Jarahy	Dug	326606	1562163	45	Domastic
ZA-053	H-0487	Al ma amrah(Al jarahy)	Dug	328006	1563170	30	Domastic
ZA-054	H-0147	AL araeesh (AL jarahy)	Dug	328521	1564731	50	Domastic
ZA-055	B-1357	Mahal Al saikh (Zabid)	Dug	329384	1566599	30	Domastic
ZA-056	H-0167	Al shat (Al garahy)	Dug	327372	1566145		Irrigation
ZA-057	F-0212	AL hamy (Zabid)	Dug	321946	1572896	50	Domastic
ZA-058	F-0340	Mahwa AL aaqel (Zabid)	Dug	323095	1571081	50	Irrigation
ZA-059	A-1950	Al Toraibah (Zabid)	Dug/Bore	325142	1574401	40	Domastic
ZA-060	A-1993	Al Toraibah (Zabid)	Dug	326224	1576736	120	Domastic
ZA-061	A-1952	Al Toraibah (Zabid)	Dug/Bore	326367	1574305	91	Irrigation
ZA-062	B-1402	Omar Area (Zabid)	Dug	330577	1568505		Domastic
ZA-063	C-1928	Al Dhahey (Zabid)	Dug/Bore	328010	1573414	100	Domastic
ZA-064	B-1547	Al mubarak (Zabid)	Dug	328967	1569479	30	Irrigation
ZA-065	B-1179	Al Shabariq (Zabid)	Dug/Bore	329879	1571912		Domastic
ZA-066	G-0521	Al Jarahy	Bore	327697	1559648	65	Domastic
ZA-067	H-0117	bait Awon (Al garahy)	Dug	328807	1561080	45	Domastic
ZA-068	B-0917	Al Barh	Dug	337360	1567753	26	Domastic
ZA-069	B-0921	A'amer Al Olia	Dug/Bore	335824	1566594	51	Supply
ZA-070	B-1025	Al Jahafiah (Al Jarahy)	Dug	333219	1568794	63	Irrigation
ZA-071	B-1137	Mahwa Souleiman	Dug/Bore	332454	1571330	145	Supply
ZA-073	B-985	Al Sona'a (Al Jarahy)	Dug	337037	1571454	23	Irrigation
ZA-074	B-981	Al Taweilah (Al Jarahy)	Dug	338856	1570926	21	Supply
ZA-075	B-1226	Wadi Shadad	Bore	338133	1576061	130	Supply
ZA-076	B-1242	AL swaidih (Zabid)	Dug	335310	1575901	64	Irrigation
ZA-077	D-1779	Blad Al rquod (Zabid)	Dug/Bore	330953	1578252	105	Domastic
ZA-078	D-1773	Mahwa Al zaine(Zabid)	Dug/Bore	329840	1575614	95	Domastic
ZA-079	B-1258	Mahwa AL kaby(Zabid)	Dug	332900	1575810	81	Domastic
ZA-080	B-0989	Aqby (Al Jarahy)	Dug	335626	1569868	65	Supply
ZA-081	C-1290	Zabid	Bore	319056	1569644	100	Supply
ZA-082	B-1221	Mahwa Bihlool	Dug	336096	1573318		Domastic
ZA-083	B-1203	Al Mawqer (Al Jarahy)	Dug/Bore	333532	1571928	120	Supply
ZA-084	B-1215	Gabal Ahmad	Dug	337816	1572883	9	Domastic
ZA-085	A-1768	Al Qudasy (Al Jarahy)	Dug	329675	1553652	45	Domastic
ZA-086	A-1746	Al Qudasy (Al Jarahy)	Dug	330252	1550503	40	Domastic

Sample No.	Well No.	Site	Well Type	UTM East	UTM North	Total Depth (m)	Water Use
ZA-087	A-1740	Al Qudasy (Al Jarahy)	Dug	332961	1548918	36	Irrigation
ZA-088	A-1731	Al Kabah Al Hamra'a (Al Jarahy)	Dug	335058	1549908	30	Domastic
ZA-089	A-1722	Al Abadeyah Al Olya (Al Jarahy)	Dug	336731	1550420	25	Domastic
ZA-090	A-1679	Al Abadeyah Al Sofla (Al Jarahy)	Dug	335563	1552620	33	Domastic
ZA-091	A-1661	Wadi Al Mohayfer (Al Jarahy)	Dug	337280	1554416	11	Domastic
ZA-092	A-1699	Bait Al Zain (Al Jarahy)	Dug	332247	1551970	60	Irrigation
ZA-093	A-1631	Al Rab'ey (Al Jarahy)	Dug	332058	1554544	55	Irrigation
ZA-094	A-1415	Al Mezjajy (Al Jarahy)	Dug	333805	1556429	55	Irrigation
ZA-095	A-1481	Al Wasel (Al Jarahy)	Dug	331025	1556802	38	Domastic
ZA-096	A-1406	Al Jar (Al Jarahy)	Dug/Bore	333963	1558654	90	Irrigation
ZA-097	A-1444	Al Torbah (Al Jarahy)	Dug	336040	1559266		Irrigation
ZA-098	A-1368	Al Ratekh(Al Jarahy)	Dug	336903	1560803	73	Supply
ZA-099	A-1396	Al Jar (Al Jarahy)	Dug	335045	1560761	70	Domastic
ZA-100	A-1354	Al Jar (Al Jarahy)	Dug	331688	1560584	40	Domastic
ZA-101	A-1326	Mahwa Al Moshara'a (Al)	Dug	334184	1563346	54	Irrigation
ZA-102	A-1175	Al Marabid (Al Jarahy)	Dug	337829	1563227	93	Irrigation
ZA-103	A-1142	Al Jerbah (Al Jarahy)	Bore	332141	1565049	75	Supply
ZA-104	E-1773	Al Masahib (Al Jarahy)	Dug	325139	1563751	30	Domastic
ZA-106	A-1830	She'ab Al Okdah (Al Jarahy)	Dug	325460	1556974	20	Domastic
ZA-107	A-1858	Al Okdah (Al Jarahy)	Dug	324272	1554671	23	Domastic
ZA-108	G-0461	Al Sho'aib (Al Jarahy)	Dug	323381	1560799		Domastic
ZA-109	G-0269	Al Shobaita'a (Al Jarahy)	Dug/Bore	319461	1563251	54	Domastic
ZA-110	G-0352	Al Raweyah(Al Tuhayta)	Dug	314297	1561424	66	Irrigation
ZA-111	G-0362	Owain (Al Jarahy)	Bore	311159	1562235	120	Irrigation
ZA-112	C-1605	Mahwa Al Jal'oom (Al Tuhayta)	Dug	308160	1561726	120	Irrigation
ZA-113	A-1998	Mahwa Al basah (Zabid)	Dug	327343	1571593		Irrigation
ZA-114	B-1274	Al Habil (Zabid)	Dug/Bore	331275	1574140		Irrigation
ZA-115	D-1092	Al Matinah	Dug	297680	1553244	10	Irrigation
ZA-116	D-1150	Al Sakf	Dug	298451	1551072	4	Domastic
ZA-117	D-1202	Al Sakf	Dug	299609	1550424	20	Domastic
ZA-118	D-1168	Al Baka'ah	Dug	299912	1548522	3	Domastic
ZA-119	D-1326	Al Mulikid	Dug	301686	1552690	21	Irrigation
ZA-120	D-1378	Al Gabaliah	Dug	302158	1555933	30	Irrigation
ZA-121	D-1752	Al Gabaliah	Dug/Bore	303601	1555894	33	Irrigation
ZA-122	C-1700	Al Gabaliah	Dug/Bore	304150	1558015	45	Irrigation
ZA-123	D-1334	Al Abadiah	Dug/Bore	305219	1551274	30	Irrigation
ZA-124	D-1824	Al Gabaliah	Dug/Bore	304415	1554265	30	Irrigation
ZA-125	A-1862	Al A'Akdah	Dug	323965	1551628	30	Domastic
ZA-126	A-1940	Wadi Al Fwahah	Dug	319137	1548590	44	Domastic
ZA-127	H-0124	Ashargah	Dug/Bore	324815	1547742	65	Irrigation
ZA-128	C-1817	Al Jabaleyah(Al Tohayta)	Dug/Bore	306647	1558823		Irrigation
ZA-129	C-1640	Al Meghras	Dug/Bore	305460	1561395		Irrigation

Sample No.	Well No.	Site	Well Type	UTM East	UTM North	Total Depth (m)	Water Use
Re-001	D-0714	Darban Village	Dug/Bore	324538	1579965	90	Supply
Re-002	E-0504	Al Shadhelliah	Dug/Bore	326874	1582809	125	Irrigation
Re-003	D-0133	Al Madan	Dug/Bore	330774	1585426	113	Irrigation
Re-004	D-0124	Ad Demnah	Dug/Bore	332105	1589676	90	Supply
Re-005	C-0145	Al Garobah	Bore	329172	1591012	120	Irrigation
Re-006	E-0373	Al Munaibr	Dug/Bore	316307	1591463	70	Irrigation
Re-007	E-0316	Al Fuashek	Dug/Bore	314306	1592233	96	Irrigation
Re-008	E-0188	Al Masarif	Dug/Bore	320518	1593585	80	Irrigation
Re-010	E-0419	As Sulikiah	Dug/Bore	318888	1600185	85	Irrigation
Re-011	E-0226	Al Gumaniah	Dug/Bore	319652	1597589	90	Supply
Re-012	D-0773	Al Badwah	Dug/Bore	318159	1575585	108	Salt Factory
Re-013	D-0765	Al Hutah	Dug/Bore	322843	1576997	80	Irrigation
Re-014	E-0549	Al Baratah	Dug/Bore	327725	1578004	70	Supply
Re-015	E-0460	Bait Al Wali	Dug/Bore	329640	1582161	92	Supply
Re-016	D-0007	Meshrafah	Dug/Bore	345975	1589585	30	Supply
Re-017	D-0087	Bany Mua'amer	Dug/Bore	336421	1587103	83	Domastic
Re-018	C-0068	Al Ghwader	Dug/Bore	334612	1590421	54	Irrigation
Re-019	C-0288	Al Ghwader	Dug/Bore	337979	1590896	70	Irrigation
Re-020	C-0227	Al Habily	Dug/Bore	340115	1591612	60	Supply
Re-021	E-0425	Al Ghanikah	Dug/Bore	334020	1582628	110	Supply
Re-022	E-0433	Wadi Kuhfah	Dug/Bore	335200	1580341	85	Supply
Re-023	E-0429	Mudmen Arrekood	Dug	336709	1581400	78	Supply
Re-024	D-0140	Al Mehsam	Dug/Bore	330449	1588122	100	Supply
Re-025	D-0330	Biot Al Gundg	Dug/Bore	328327	1585079	100	Irrigation
Re-026	D-0325	Bait Hageb	Dug/Bore	323732	1583456	120	Irrigation
Re-027	D-0438	Mahwa Al Maky	Bore	319579	1582754	125	Irrigation
Re-028	D-0232	Hesy Esmaeil Village	Dug/Bore	321201	1585973	120	Irrigation
Re-029	C-0384	Al Husainiah	Bore	318200	1586112	100	Supply
Re-030	C-0114	Al Kuhaim	Dug/Bore	323603	1587949	110	Supply
Re-031	C-0121	Biot Al Dahaliah	Bore	320942	1588147	120	Domastic
Re-032	C-0136	Al Omariah	Dug/Bore	320965	1590330	110	Supply
Re-033	E-0069	Al Fash Village	Dug/Bore	338663	1594668	48	Irrigation
Re-034	C-0096	Al Mandab	Dug	334652	1595958	61	Irrigation
Re-035	E-0039	Al Hajeb	Dug	342423	1599490	8	Irrigation
Re-036	E-0108	Al Gumaeiah	dug	335310	1599147	47	Supply
Re-037	E-0117	Al Mationiah	Dug	330420	1600120	75	Supply
Re-038	E-0129	Al Mabkariah	Dug	328104	1597932	70	Supply
Re-039	E-0121	Al Kanidah Al Gharbiah	Dug	330668	1596109	75	Supply
Re-040	C-0330	Al Garobah	Dug/Bore	331630	1592820	173	Irrigation
Re-041	C-0631	AL MUKHARIF	Dug/Bore	314352	1583915	160	Irrigation
Re-042	C-0419	AL ARISH	Dug/Bore	312925	1585067	120	Irrigation
Re-043	E-0633	AL MAHAT	Dug/Bore	315907	1581332	75	Supply
Re-044	C-0724	AL MURRAH	Dug/Bore	312443	1582001	80	Supply
Re-045	E-0681	ARRUKBAH	Dug/Bore	318116	1578912	66	Irrigation
Re-046	B-0216	AL MABKARIAH	Dug/Bore	307221	1580711	87	Irrigation

Sample No.	Well No.	Site	Well Type	UTM East	UTM North	Total Depth (m)	Water Use
Re-047	B-0135	AL MADINAH	Dug/Bore	304479	1579580	75	Irrigation
Re-048	B-0101	AL MADINAH	Dug/Bore	303200	1579684	70	Supply
Re-049	B-0209	AL HAWALY	Dug/Bore	308391	1582819	90	Supply
Re-050	B-0089	AL MADINAH	DUG	300904	1579617	24	Domastic
Re-051	B-0074	AS SHAMIA	DUG	296359	1579533	24	Domastic
Re-052	B-0277	AL KUBAIBAH	Dug/Bore	310407	1581037	70	Irrigation
Re-053	B-0028	ATTOR	DUG	291925	1578885	18	Domastic
Re-054	B-0019	AL MAHAMERAH	DUG	290062	1577951	2	Domastic
Re-055	B-0003	AL MAHAMERAH	DUG	289171	1580009	2	Domastic
Re-056	A-0041	MAABAR AL GAH	DUG	288176	1583367	3	Domastic
Re-057	B-0402	AL GHANNMIAH	Dug/Bore	308998	1588833	36	Supply
Re-058	B-0507	AL TAMAMIAH	Dug/Bore	305145	1589427	66	Irrigation
Re-059	B-0534	AL MASHAWRIAH	Dug/Bore	301035	1588636	30	Irrigation
Re-060	B-0580	WADI AL GAH	Dug/Bore	298628	1587290	36	Irrigation
Re-061	B-0416	AL GHANMIAH	Dug/Bore	306493	1587935	42	Irrigation
Re-062	B-0632	SOL AZZAHR	Dug/Bore	298082	1589002	40	Irrigation
Re-063	E-0259	WADI ADDIAH	Dug/Bore	303049	1589702	43	Irrigation
Re-064	A-0528	AL MARAZEKAH	Dug	290952	1584558	31	Irrigation
Re-065	A-0101	ASHWATABAH	Dug	288954	1584848	8	Irrigation
Re-066	D-0842	Assafariah	Dug	287348	1588907	6	Domastic
Re-067	A-0919	Al Gah	Dug	290657	1588305	9	Domastic
Re-068	D-0828	Al Gerabi	Dug	290864	1589919	11	Domastic
Re-069	A-0889	Al Masharemah	Dug	292247	1586074	26	Irrigation
Re-070	A-0259	Osh Al Gemal	Dug	290387	1585944	30	Irrigation
Re-071	B-0096	Al Kashaeiah	Dug	292831	1582967	19	Domastic
Re-072	B-0722	Al Khareseah	Dug/Bore	294373	1585921	36	Irrigation
Re-073	B-0812	Al Khareseah	Dug/Bore	295799	1587112	35	Irrigation
Re-074	E-0707	Al Rous	Dug/Bore	294469	1587724	35	Supply
Re-075	E-0339	Bany Al Murair	Bore	316772	1596600	80	Supply
Re-076	E-0237	Al Mahabib	Dug/Bore	312589	1596894	143	Supply
Re-077	E-0244	Al Salehiah	Dug	309320	1594704	44	Domastic
Re-078	B-0571	Adduhsheiah	Dug/Bore	308437	1592420	70	Irrigation
Re-079	E-0252	Adduhsheiah	Dug/Bore	305540	1592563	60	Irrigation
Re-080	B-0543	Al Mahdiah	Dug/Bore	300972	1586520	70	Irrigation
Re-081	B-0377	Al Ghanemiah	Dug/Bore	310208	1586791	60	Irrigation
Re-082	C-0539	Al Husam	Bore	313726	1588166	75	Irrigation
Re-083	E-0138	Al Maradefah	Dug/Bore	323900	1599549	75	Supply
Re-084	E-0163	Al Ma'arif	Dug/Bore	324178	1594856	115	Supply
Re-085	E-0144	Al Fwashek	dug	321444	1596669	58	Supply
Re-086	E-0185	Al Ghawanem	Dug/Bore	319408	1591220	66	Supply
Re-087	E-0295	Addobahei	Dug/Bore	316992	1593663	60	Irrigation
Re-088	C-0206	Bany Al Ashram	Bore	318484	1589578	100	Supply
Re-089	C-0355	Al Husainiah	Bore	318273	1587915	100	Supply
Re-090	C-0814	Al Musha'asha'eiah	Bore	312943	1577856	105	Irrigation
Re-091	B-0163	Azzaweiah	Dug/Bore	307488	1578269	80	Supply

Sample No.	Well No.	Site	Well Type	UTM East	UTM North	Total Depth (m)	Water Use
Re-092	B-0054	Al Wareiah	Dug	295910	1576574	25	Domastic
Re-093	D-0559	Al Salab	Dug/Bore	321556	1581303	90	Irrigation
Re-094	E-0444	Assaid Yosef	Dug/Bore	331936	1577628	110	Irrigation
Re-095	C-0023	Al Habily	Dug	342196	1589405	18	Irrigation
Re-096	E-0011	Sheb Al Shami	Dug	342326	1595992	20	Domastic
Re-097	E-0225	Al Arageshah	Dug/Bore	324388	1591028	99	Irrigation
Re-099	C-0340	Mahwa Al Boihely	Dug/Bore	332889	1586802	100	Irrigation
Re-100	D-0186	Al Arba'ein	Dug/Bore	326711	1589125	90	Irrigation

Annex III: Chemical Analysis Results For The Study Area (mg/l)

Sample No.	E.C	pH	TDS	DO	Ca	Mg	Na	K	Fe	Cl	So4	Hco3	Co3	No3	F	SAR	TA	TH
ZA-1	1283	7.5	821	3.8	88	31	131	3.315	0.42	99	154	384	Nil	31.4	0.4	3.05	200	350
ZA-2	1038	7.4	664	3.39	46	41	104	3.5	0.52	53	130	366	Nil	8	0.8	2.7	200	287
ZA-3	1298	7.1	831	2.88	50	60	122	3.04	0.48	82	173	427	Nil	4	0.35	2.7	200	377
ZA-4	986	7.3	631	2.96	66	22	106	3.588	0.493	110	125	244	Nil	8	0.4	2.9	180	257
ZA-5	956	7.2	612	3.8	50	32	99	2.535	0.49	78	58	366	Nil	6	0.45	2.7	200	259
ZA-6	1026	7.1	657	3.66	30	52	101	2.574	0.5	60.4	115	366	Nil	5.5	0.6	2.58	200	293
ZA-7	985	7.3	630	3.33	50	31	108	1.833	0.53	60.4	125	305	Nil	32.8	0.4	2.94	200	255
ZA-8	981	7.1	628	3.33	60	29	99	3.276	0.52	68	130	305	Nil	10	0.55	2.62	200	272
ZA-9	1374	7.1	879	4.12	88	32	150	3.783	0.52	131	182	366	Nil	10	0.46	3.45	220	354
ZA-10	1314	7.2	841	3.38	108	26	124	3.159	0.52	124	134	366	Nil	51	0.45	2.77	240	379
ZA-11	1133	7.2	725	3.82	80	34	101	2.574	0.53	96	163	305	Nil	12	0.6	2.39	220	343
ZA-12	1207	7.5	657	3.82	70	24	108	2.749	0.5	89	120	305	Nil	15	0.45	2.887	220	267
ZA-13	921	7.3	589	3.41	60	22	99	2.613	0.53	53	77	305	Nil	64.8	0.55	2.78	180	242
ZA-14	1008	7.4	645	3.29	56	30	106	2.691	0.53	89	62	366	Nil	15.6	0.35	2.826	180	266
ZA-15	1029	7.5	659	3.45	52	29	120	2.96	0.52	96	120	305	Nil	4.5	0.5	3.23	180	252
ZA-16	1291	7.2	826	3.37	64	38	147	3.705	0.54	160	187	244	Nil	26.6	0.55	3.58	160	320
ZA-17	1286	7.2	823	3.2	42	43	161	4.095	0.5	128	178	305	Nil	32	0.5	3	200	361
ZA-18	1553	7.2	994	3.4	86	44	170	4.25	0.55	220	144	366	Nil	20	0.6	3.7	180	400
ZA-19	1012	7.3	648	4.51	52	28	115	3.588	0.55	89	91	336	Nil	11.718	0.45	3.19	160	248
ZA-20	1766	7.2	1130	3.44	116	40	193	5.07	0.58	270	187	311	Nil	64.8	0.6	3.94	140	458
ZA-21	1860	7.2	1190	3.3	100	48	216	5.46	0.56	270	182	372	Nil	64.5	0.75	4.43	180	452
ZA-22	2070	7.5	1325	3.62	90	66	244	3.9	1.12	266	230	445	Nil	67	0.5	4.74	220	502
ZA-23	2640	7.3	1690	2.82	150	78	280	7.127	0.73	462	202	488	Nil	73	0.65	4.6	200	703
ZA-24	8540	7.3	5466	1.58	232	73	1527	47.11	1.95	2535	230	488	Nil	69	0.85	22.32	200	887

Sample No.	E.C	pH	TDS	DO	Ca	Mg	Na	K	Fe	Cl	So4	Hco3	Co3	No3	F	SAR	TA	TH
ZA-26	1323	7.4	847	4.9	58	31	175	4.7	0.44	149	187	305	Nil	6.8	0.35	4.59	220	156
ZA-27	1323	7.4	847	3.13	58	31	175	4.7	0.44	149	187	305	Nil	6.8	0.35	4.59	220	156
ZA-28	908	7.2	581		74	17	90	2.19	0.52	57	110	305	Nil	10	0.45	2.4	120	256
ZA-29	1840	7.4	1178	4.31	48	52	267	4.1	0.52	320	110	366	Nil	65	0.56	6.3	200	338
ZA-30	1376	7.6	881	2.93	62	36	173	4.7	0.55	160	144	366	Nil	15	0.54	4.3	160	306
ZA-31	1198	7.6	767	2.55	52	26	161	5.46	0.54	107	134	366	Nil	10	0.45	4.5	200	224
ZA-32	4010	8.2	2566	4.61	66	58	725	18.33	0.33	852	307	488	15	69	0.89	15.66	160	409
ZA-33	1042	7.9	667	3.69	30	22	161	4.1	0.72	89	110	305	Nil	37.57	0.5	5.4	200	167
ZA-34	954	7.7	611	3.11	32	24	133	3.393	1.13	85	96	305	Nil	8.742	0.45	4.3	160	181
ZA-35	1663	8.2	1064	4.13	40	17	299	7.6	0.62	337	96	244	15	35	0.55	10	120	171
ZA-36	1706	7.7	1092	5.46	54	32	265	6.7	0.62	320	149	275	Nil	25	1.349	7.18	120	269
ZA-37	932	7.4	597	3.07	58	19	108	3	0.5	75	48	366	Nil	13	0.52	3.13	160	225
ZA-38	1142	7.4	731	2.88	68	38	109	2.7	0.55	92	120	366	Nil	15	0.56	2.61	180	330
ZA-39	1659	7.6	1062	2.99	126	25	184	6.63	0.6	206	264	305	Nil	15	0.67	3.9	180	420
ZA-40	1002	7.7	641	3.19	46	32	113	3.2	0.65	71	91	366	Nil	10	0.56	3.1	140	249
ZA-41	1980	7.8	1267	2.94	114	58	212	4.2	0.07	284	221	427	Nil	12.5	0.39	4	180	529
ZA-42	987	7.9	632	3.13	62	23	110	2.7	0.61	96	86	305	Nil	21.4	0.52	3.04	200	252
ZA-43	948	7.8	607	3.1	54	20	115	2.9	1.96	85	91	305	Nil	10	0.54	3.4	120	517
ZA-44	1081	7.7	692	3.45	58	19	143	3.4	0.5	107	77	366	Nil	11	0.52	4.13	160	225
ZA-45	1125	7.8	720	4.44	64	22	143	2.1	0.37	114	43	427	Nil	7	0.56	3.9	200	252
ZA-46	9040	7.5	5786	3.63	180	192	1495	13.9	0.64	2521	432	610	Nil	24.9	0.304	18.4	120	1256
ZA-47	5750	8.7	3680	2.1	300	360	281	10.1	0.25	1331	96	915	75	27.3	1.14	2.6	440	2262
ZA-48	1361	7.5	871	3.5	98	24	152	4.29	0.38	139	115	427	Nil	15	1.41	3.6	340	346
ZA-49	1368	7.6	876	4.09	74	28	175	2	0.07	124	96	458	Nil	38	1.35	4.4	140	303
ZA-50	2000	7.5	1280	2.5	124	38	239	7.22	0.55	192	134	671	Nil	44	1.549	4.8	260	470
ZA-51	2670	8.2	1709	2.22	30	32	515	2	0.38	462	144	610	7.5	23.6	1.22	15.5	300	209
ZA-52	1078	7.8	690	3.5	54	28	131	3.28	0.15	178	77	244	Nil	8	0.93	3.6	140	253

Sample No.	E.C	pH	TDS	DO	Ca	Mg	Na	K	Fe	Cl	So4	Hco3	Co3	No3	F	SAR	TA	TH
ZA-53	1031	7.6	660	3.25	60	23	122	2.9	0.55	89	91	305	7.5	38	0.56	3.4	160	247
ZA-54	1350	7.6	864	3.61	90	38	131	3.3	0.48	124	96	427	7.5	44.33	0.67	2.9	200	385
ZA-55	1256	7.2	804	3.71	80	36	127	2.3	0.58	107	96	427	Nil	35	0.65	2.9	280	351
ZA-56	1208	7.6	773	3.22	68	43	113	2.8	0.34	85	62	488	Nil	22	0.55	2.6	220	351
ZA-57	1181	7.4	756	3.5	64	34	131	3.2	0.33	114	62	427	Nil	17.11	0.65	3.3	160	303
ZA-58	1781	7.1	1140	3.39	130	47	168	4.3	0.6	167	106	610	Nil	55	0.67	3.2	220	522
ZA-59	1061	7.3	679	3.6	64	34	104	3.82	0.57	92	24	427	Nil	31.4	0.11	2.6	200	303
ZA-60	1161	7.5	743	2.71	72	19	145	3.7	0.41	142	96	305	Nil	38	0.13	3.9	180	260
ZA-61	1124	7.3	719	2.73	70	26	124	3.042	0.28	107	82	366	Nil	32	0.55	3.2	220	284
ZA-62	1803	7.4	1154	3.74	62	92	163	4.1	0.66	142	110	671	Nil	43	0.69	3.1	220	541
ZA-63	1110	7.6	710	3.66	74	20	129	3.2	0.42	124	96	305	Nil	35	0.54	3.4	400	269
ZA-64	1937	7.1	1240	4.63	106	78	173	3.315	0.38	178	120	671	Nil	49	0.69	3.09	160	593
ZA-65	1265	7.4	810	3.8	88	30	129	3.3	0.64	107	96	427	Nil	38	0.48	3.02	160	346
ZA-66	881	7.8	564	2.54	40	13	129	3.3	0.56	71	62	305	Nil	30	0.41	4.5	160	155
ZA-67	964	7.6	617	3.11	64	16	115	3.59	0.66	89	77	305	Nil	33	0.52	3.3	140	227
ZA-68	1489	7.5	953	3.2	60	36	202	3.5	0.33	181	96	427	Nil	45	0.62	5	240	301
ZA-69	1201	7.5	769	3.19	70	12	170	3.66	0.22	124	86	366	Nil	39	0.63	4.9	200	225
ZA-70	1472	7.4	942	3.3	90	30	175	3.71	0.64	114	48	610	Nil	29	0.63	4.1	220	351
ZA-71	1474	7.6	943	3.53	120	13	173	4.41	0.62	178	101	427	Nil	38	0.49	4	140	355
ZA-72	1486	7.5	951		100	24	177	4.563	0.445	185	101	427	Nil	33.8	0.45	4.12	260	351
ZA-73	1372	7.4	878	2.46	80	24	175	3.94	0.6	178	96	366	Nil	44.2	0.44	4.4	180	301
ZA-74	1371	7.5	877	2.83	100	14	170	4.1	0.33	174	106	366	Nil	37	0.49	4.1	200	326
ZA-75	1320	7.2	845	3.42	90	17	166	3.9	0.38	160	96	366	Nil	40	0.41	4.2	280	296
ZA-76	1831	7.1	1172	3.3	112	30	232	4.13	0.39	309	134	366	Nil	48	0.65	5	180	406
ZA-77	1813	6.9	1160	2.8	130	36	196	4.8	0.39	330	96	366	Nil	49	0.67	3.9	180	476
ZA-78	1231	7.3	788	3.32	80	11	168	3.55	0.35	192	62	305	Nil	37	0.45	4.7	140	246
ZA-79	1033	7.3	661	3.56	60	24	120	3.5	0.38	107	82	305	Nil	35	0.41	3.3	200	251

Sample No.	E.C	pH	TDS	DO	Ca	Mg	Na	K	Fe	Cl	So4	Hco3	Co3	No3	F	SAR	TA	TH
ZA-80	1297	7.3	831	1.02	64	19	184	4.7	0.38	181	58	366	Nil	40	0.52	5.2	160	240
ZA-81	1340	7.5	858	4.3	80	29	159	4.2	0.34	149	72	427	Nil	42	0.46	3.9	180	322
ZA-82	1445	7.7	925	2.83	56	22	223	4.73	0.53	178	86	427	Nil	38	0.56	6.4	240	232
ZA-83	1210	7.3	774	3.46	64	14	175	2.93	0.46	146	62	366	Nil	44	0.07	5.1	160	219
ZA-84	1489	7.5	953	2.24	116	14	179	1.2	0.48	185	86	427	Nil	52	0.57	4.2	320	349
ZA-85	1112	7.9	712	2.89	60	19	147	3.705	0.364	153	58	305	Nil	35	0.51	4.2	160	230
ZA-86	1203	7.3	770	3.11	68	22	154	4.212	0.53	156	48	366	Nil	35	0.48	4.2	140	262
ZA-87	2700	7.8	1728	4	160	29	380	1.36	0.55	497	312	366	Nil	28	0.92	7.15	200	522
ZA-88	1800	7.8	1152	3.02	60	24	297	2.26	0.43	249	158	427	Nil	44	0.52	8.1	240	251
ZA-89	1829	8	1171	3.92	94	13	285	2.61	0.39	249	96	488	15	44	0.59	7.2	260	290
ZA-90	1829	7.6	1171	2.97	80	13	301	1.599	0.6	245	125	488	Nil	48	0.59	8.14	240	255
ZA-91	1865	7.4	1194	3.3	120	25	242	1.76	0.11	249	134	488	Nil	48	0.63	5.2	240	405
ZA-92	1367	7.7	875	4.4	88	24	166	2.5	0.14	195	125	305	Nil	35	0.45	4	160	421
ZA-93	1043	7.7	668	3.53	64	13	138	2.5	0.13	124	67	305	Nil	31	0.42	4.1	200	215
ZA-94	1016	7.6	650	3.91	66	13	131	1.7	0.18	107	77	305	Nil	33	0.47	3.8	120	220
ZA-95	1058	7.6	677	4.38	62	17	138	3.4	0.32	142	58	305	Nil	22	0.52	4	120	226
ZA-96	926	7.6	593	2.38	54	18	115	2.5	0.13	110	48	305	Nil	8.7	0.44	3.5	140	211
ZA-97	1277	7.3	817	3.47	74	20	168	1.72	0.13	185	58	366	Nil	21.3	0.49	4.4	160	271
ZA-98	1367	7.3	875	2.84	70	22	191	1.7	0.1	178	62	427	Nil	21	0.61	5.1	160	267
ZA-99	1067	7.7	683	3.41	48	25	140	1.72	0.25	153	58	305	Nil	8.5	0.62	4.1	160	225
ZA-100	1257	7.9	805	2.85	76	32	138	1.72	0.38	185	53	366	Nil	14.6	0.65	3.4	180	324
ZA-101	1256	7.5	804	3.24	70	19	170	1.76	0.34	153	53	427	Nil	8.8	0.34	4.6	200	369
ZA-102	1303	7.5	834	4.05	74	16	184	1.7	0.42	160	62	427	Nil	12.9	0.42	5.1	220	252
ZA-103	1072	7.6	686	2.54	54	23	138	1.72	0.39	142	29	366	Nil	6.1	0.444	4	200	232
ZA-104	1310	7.8	838	4.11	60	19	193	2.5	0.59	167	58	427	Nil	11	0.44	5.5	200	305
ZA-105	1071	7.7	685		64	22	129	3.4	0.58	149	53	305	Nil	23.12	0.51	3.5	180	252
ZA-106	1190	7.5	762	2.7	74	24	140	3.4	0.55	163	58	366	Nil	5.1	0.35	3.6	200	286

Sample No.	E.C	pH	TDS	DO	Ca	Mg	Na	K	Fe	Cl	So4	Hco3	Co3	No3	F	SAR	TA	TH
ZA-107	1143	7.7	732	2.73	64	24	140	2.5	0.59	142	58	366	Nil	13	0.35	3.8	200	261
ZA-108	1009	7.7	646	2.52	54	13	143	2.5	0.6	124	48	329	Nil	10.7	0.32	4.5	160	190
ZA-109	1324	7.7	847.4	3.1	68	20	184	3.4	0.58	167	62	427	Nil	13.8	0.33	5	220	254
ZA-110	1149	7.6	735	3.73	60	20	154	3.3	0.6	117	48	427	Nil	10.3	0.46	4.4	220	234
ZA-111	1200	7.4	768	2.95	60	30	147	3	0.37	131	58	427	Nil	5.2	0.32	3.9	220	276
ZA-112	1248	7.3	799	2.55	60	31	156	1.7	0.58	107	58	488	Nil	15.9	0.45	4.1	240	280
ZA-113	1357	7.3	869		90	28	152	5.15	0.58	142	67	488	Nil	9.05	0.46	3.6	220	343
ZA-114	1277	7.5	817		92	12	161	5.46	0.33	142	72	427	Nil	15.4	0.42	4.2	200	280
ZA-115	15610	8.1	9990	4.36	390	210	2721	30.7	0.34	3284	2016	976	Nil	344.3	0.9	27.5	440	1857
ZA-116	1955	7.9	1251	3.2	38	20	363	4.3	0.58	302	168	397	Nil	63	0.63	11.78	220	179
ZA-117	2160	7.8	1382	2.3	40	30	391	3.5	0.54	426	154	366	Nil	23.13	0.51	11.33	180	226
ZA-118	1724	8.1	1103.4	4.8	40	19	311	4.3	0.66	295	120	366	Nil	25.8	0.45	10.06	200	180
ZA-119	1691	7.6	1082	3.16	72	36	235	3.5	0.48	295	110	366	Nil	17.4	0.56	5.6	180	331
ZA-120	2310	7.5	1478	3.03	86	64	308	2	0.6	447	163	427	Nil	4.8	0.43	6.1	220	484
ZA-121	2210	7.4	1414	3.9	54	73	304	3.4	0.58	408	158	427	Nil	17.3	0.41	6.3	240	442
ZA-122	1731	7.4	1108	3.24	56	56	223	2.5	0.58	320	106	366	Nil	4.2	0.82	5	220	375
ZA-123	995	7.8	637	4.69	48	17	138	3.4	0.53	124	48	305	Nil	25	0.52	4.4	140	191.4
ZA-124	1342	7.6	859	4	52	25	198	3.4	0.63	178	77	397	Nil	18.4	0.44	5.6	200	235
ZA-125	1014	7.6	649	4.75	60	19	124	4.2	0.61	107	48	366	Nil	7.3	0.41	3.6	200	230
ZA-126	963	7.9	616	4.02	54	11	136	4.2	1.42	117	48	305	Nil	19	0.41	4.4	140	181
ZA-127	1342	7.4	859	3.52	52	25	198	4.2	0.58	185	72	397	Nil	12.3	0.41	5.6	160	235
ZA-128	1183	7.4	757		54	26	159	1.33	0.32	124	58	427	Nil	6.7	0.41	4.4	220	244
ZA-129	1482	7.3	949		48	48	191	4.2	0.58	249	82	366	Nil	6.8	0.35	4.6	220	322
Re - 01	1144	7.8	732	4.55	90	42	76	5.8	0.27	110	101	366	Nil	12	0.5	1.7	240	401
Re - 02	972	7.4	622	3.73	56	42	76	3.5	0.27	82	58	366	Nil	11	0.7	1.9	200	316
Re - 03	1033	7.4	661	3.77	40	60	74	0.98	0.28	89	110	305	Nil	30	0.15	1.76	200	352
Re - 04	1011	7.3	647	6.57	90	29	69	5.7	0.28	71	120	305	Nil	35	0.5	1.6	220	351

Sample No.	E.C	pH	TDS	DO	Ca	Mg	Na	K	Fe	Cl	So4	Hco3	Co3	No3	F	SAR	TA	TH
Re - 05	1099	7.2	703	4.08	48	52	94	5.8	0.32	142	38	366	Nil	7.5	1	2.29	220	338
Re - 06	1229	7.2	787	3.9	110	30	97	3.9	0.27	135	134	305	Nil	40	0.31	2.1	180	401
Re - 07	1222	7	782	5.62	106	30	99	3.5	0.31	142	125	305	Nil	35	1	2.18	140	391
Re - 08	917	7.9	587	5.48	80	24	71	2.5	0.31	89	26	336	Nil	6	0.5	1.8	220	301
Re - 09	905	7.9	579		80	18	78	3	0.27	78	72	305	Nil	18	0.4	2.05	200	275
Re - 10	1053	7.8	674	3.97	100	20	85	5	0.28	128	72	305	Nil	23	0.7	2.02	160	334
Re - 11	998	7.1	639	5.61	90	18	90	2.964	0.28	78	115	305	Nil	20	0.8	2.3	180	301
Re - 12	961	7.4	615	3.04	60	26	99	2.57	0.3	92.3	86	305	Nil	13.1	0.41	2.7	220	259
Re - 13	977	7.1	625	3.3	70	18	106	3.59	0.31	71	120	305	Nil	16	0.45	2.91	220	251
Re - 14	1838	7	1176	3.89	68	82	184	3.705	0.364	280	192	336	Nil	56	0.45	3.54	120	504
Re - 15	1038	7.1	664	3.77	100	18	85	2.808	0.27	82	130	305	Nil	22	0.47	2	160	317
Re - 16	1529	7.1	979	4.9	150	30	120	3.04	0.35	185	75	488	Nil	31	0.6	2.33	140	501
Re - 17	1105	7.2	707	4.17	86	25	106	2.418	0.295	78	120	366	Nil	19	0.52	2.57	160	320
Re - 18	1137	7.2	728	4.4	110	28	81	2.652	0.27	71	101	427	Nil	15.4	0.6	2.11	140	393
Re - 19	1297	7	830	1.95	102	38	106	2.81	0.37	96	125	427	Nil	38	0.65	2.3	180	415
Re - 20	1023	7.8	655	4.1	74	28	94	3.198	0.53	71	139	305	Nil	19	0.56	2.37	160	303
Re - 21	1046	7.3	669	3.76	96	26	76	2.379	0.37	107	62	366	Nil	8	0.54	1.817	140	349
Re - 22	997	7.2	638	1.55	82	24	85	2.886	0.42	57	106	366	Nil	9.1	0.43	2.1	180	276
Re - 23	1011	7.7	647	4.4	74	23	101	3.432	0.44	53	155	305	Nil	22	0.52	2.63	140	252
Re - 24	1292	7.3	827	4.25	96	19	147	3.471	0.42	99	173	366	Nil	31.4	0.23	3.58	140	320
Re - 25	999	7.2	639	2.84	76	22	99	3.354	0.27	78	115	305	Nil	24	0.7	2.57	140	282
Re - 26	915	7.2	586	4	74	23	81	2.028	0.27	64	96	305	Nil	20	0.74	2.09	120	282
Re - 27	1112	7.2	712	3.68	100	28	87	0.963	0.27	107	178	244	Nil	24	0.62	2	160	368
Re - 28	1257	7.1	804	4	128	19	104	2.633	0.31	96	158	336	Nil	32	0.72	2.25	160	400
Re - 29	933	7.5	597	3.94	88	14	83	2.11	0.27	75	91	305	Nil	19.2	0.71	2.17	180	274
Re - 30	926	7.2	593	4.12	88	16	81	2.1	0.27	53	155	305	Nil	19.2	0.9	2.09	200	282
Re - 31	993	7.4	636	3.98	86	18	92	3.12	0.509	64	110	336	Nil	19	0.65	2.35	140	291

Sample No.	E.C	pH	TDS	DO	Ca	Mg	Na	K	Fe	Cl	So4	Hco3	Co3	No3	F	SAR	TA	TH
Re - 32	1031	7.3	660	3.6	92	22	87	2.964	0.65	78	130	305	Nil	24	0.7	2.12	120	322
Re - 33	1724	7.2	1103	4.09	150	17	189	3.432	0.86	185	240	366	Nil	58	1.05	3.9	120	446
Re - 34	1216	7.3	778	3.46	106	20	117	2.5	0.47	107	168	305	Nil	40	0.5	2.7	180	349
Re - 35	1654	7.2	1059	3.15	108	19	216	3.24	0.56	163	120	549	Nil	22	0.69	5.02	180	350
Re - 36	2650	6.9	1695	3.6	160	54	317	3.9	0.64	533	216	366	Nil	60	0.73	5.54	80	623
Re - 37	1774	7.6	1135	3.7	90	37	230	2.8	0.46	238	197	366	Nil	54	0.64	5.13	80	380
Re - 38	1482	7.1	949	2.89	64	50	145	3.666	0.784	124	77	549	Nil	44	0.55	3.3	140	372
Re - 39	1262	6.9	808	2.58	50	40	154	3.939	0.812	107	134	366	Nil	48	0.56	3.9	200	293
Re - 40	1144	7.2	732	4.26	48	41	127	3.237	0.3	85	110	366	Nil	42	0.49	3.2	120	292
Re - 41	1041	7.3	666	4	80	26	94	2.3	0.224	82	125	305	Nil	32	0.52	2.4	120	309
Re - 42	1169	7.4	748	3.44	80	31	115	2.9	0.78	107	125	366	Nil	32	0.48	2.75	160	330
Re - 43	1029	7.3	659	3.25	76	17	115	2.9	0.52	96	110	305	Nil	15	0.48	3.1	140	261
Re - 44	1183	7.3	757	4.02	96	17	129	0.983	0.28	121	86	366	Nil	37.5	0.54	3.2	120	311
Re - 45	1536	7.2	983	2.11	80	36	191	2.15	0.887	178	115	427	Nil	59	0.35	4.4	120	351
Re - 46	1263	7.5	808	3.63	48	40	156	2.5	0.34	121	125	366	Nil	38	0.64	4.03	140	288
Re - 47	1056	7.5	676	3.21	42	40	115	2.925	1.019	89	134	305	Nil	15	0.56	3.04	160	273
Re - 48	987	7.5	632	3.2	46	30	115	1.2	1.002	89	96	305	Nil	20	0.45	3.2	160	241
Re - 49	975	7.5	624	3.55	32	34	122	1.52	0.978	60	120	305	Nil	32	0.45	3.6	160	223
Re - 50	1339	7.2	857	4.2	54	28	191	2.7	0.978	149	134	342	Nil	45	0.64	5.3	140	253
Re - 51	1185	7.9	758	3.27	28	17	207	2.3	0.96	142	110	305	Nil	32	0.45	7.75	140	137
Re - 52	1169	7.5	748	3.51	72	24	138	3.51	0.96	110	144	305	Nil	32	0.56	3.6	140	281
Re - 53	3010	7.7	1926	3.08	160	60	386	9.1	0.887	710	211	305	Nil	38	0.75	6.6	120	652
Re - 54	3340	7.9	2138	2.81	112	82	476	8.97	0.939	870	192	244	Nil	52	0.82	8.4	100	624
Re - 55	4430	7.9	2835	3.5	70	14	909	3.4	0.901	1172	197	366	Nil	54.3	6.175	25.77	220	234
Re - 56	1970	8.4	1261	4.14	40	24	359	3	0.756	391	96	366	15	8.8	0.65	11	200	201
Re - 57	1189	7.6	761	3.8	70	24	145	3.51	0.69	142	110	305	Nil	32	0.52	3.8	160	276
Re - 58	1377	7.4	881	3.65	80	29	166	4.1	0.71	178	96	366	Nil	48	0.65	4	160	603

Sample No.	E.C	pH	TDS	DO	Ca	Mg	Na	K	Fe	Cl	So4	Hco3	Co3	No3	F	SAR	TA	TH
Re - 59	1059	7.6	678	3.7	42	17	161	3	0.795	124	91	305	Nil	11	0.49	5.29	160	176
Re - 60	1770	7.4	1133	3.15	52	14	315	8.11	0.784	284	144	366	Nil	41.3	0.64	9.94	240	191
Re - 61	1140	7.4	730	3.4	48	23	161	3	0.874	163	77	305	Nil	12.4	0.42	4.8	180	217
Re - 62	1510	7.4	966	3.84	80	30	196	4.1	0.246	280	72	305	Nil	41.2	0.69	4.7	160	326
Re - 63	931	7.5	596	3.6	44	22	122	0.761	0.913	89	86	305	Nil	1.8	0.45	3.8	160	202
Re - 64	1820	7.7	1165	3.1	54	40	276	6.708	0.991	355	110	305	Nil	54	0.62	6.9	140	303
Re - 65	10040	7	6426	1.82	280	156	1649	42	0.885	2308	411	976	Nil	665	1.994	19.5	380	1355
Re - 66	2630	7.4	1683	4.41	34	35	492	12.28	0.196	568	96	427	Nil	77.6	0.92	14.1	300	229
Re - 67	1589	7.9	1017	3.22	28	16	299	7.02	0.834	320	77	305	Nil	16	0.64	11.19	180	137
Re - 68	1830	7.8	1171	3.29	56	28	299	7.6	1.03	391	96	305	Nil	20	0.55	8.1	140	258
Re - 69	1390	7.5	890	2.98	72	11	214	4.1	0.846	220	101	305	Nil	35	0.64	6.2	220	226
Re - 70	2760	7.7	1766		86	24	483	12.3	0.5	533	173	488	Nil	44	5.453	11.8	240	316
Re - 71	2020	7.7	1293	3.5	50	18	368	7.1	1.06	476	96	244	Nil	40.5	2.793	11.3	120	201
Re - 72	3460	7.3	2214	3.2	70	38	637	8	0.958	675	254	366	Nil	262	1.816	15.13	180	335
Re - 73	2360	7.3	1510	3.2	100	29	368	7.33	1.058	433	211	366	Nil	50.2	3.29	8.3	180	372
Re - 74	989	7.6	633	3.23	44	19	138	3.5	0.874	96	96	305	Nil	10.5	0.4	4.4	180	190
Re - 75	846	7.4	541	5.01	70	12	90	2.2	0.834	71	53	317	Nil	12	0.4	2.6	180	225
Re - 76	1560	7.5	998	4.16	124	22	170	5.77	0.717	231	110	336	Nil	78	1.235	3.7	140	402
Re - 77	981	7.7	628	3.95	68	12	122	4.1	1.019	107	77	305	Nil	11.5	0.46	3.6	140	220
Re - 78	1200	7.4	768	4.26	90	12	145	7.3	1.058	178	86	305	Nil	10.4	0.62	3.8	140	275
Re - 79	1616	7.3	1034	3.67	104	36	179	6.08	1.019	263	96	366	Nil	41.4	1.786	3.9	160	411
Re - 80	2560	7.6	1638	4:35	148	94	235	7.96	1.081	550	182	305	Nil	74	2.052	3.7	120	765
Re - 81	1289	7.4	825	4.06	94	13	161	3.94	0.548	178	96	305	Nil	51	1.425	4.15	140	285
Re - 82	1047	7.3	670	4.2	66	24	115	6.63	0.846	121	77	305	Nil	27	0.65	3.1	180	266
Re - 83	1200	7.4	768	4.83	96	9.6	143	5.3	0.71	117	101	366	Nil	35	0.325	3.7	240	280
Re - 84	1034	7.2	662	4.25	76	12	124	4.7	0.78	89	110	305	Nil	30	0.247	3.5	180	240
Re - 85	1115	7.2	714	5.08	84	17	124	5.1	0.706	110	115	305	Nil	35	0.32	3.14	240	286

Sample No.	E.C	pH	TDS	DO	Ca	Mg	Na	K	Fe	Cl	So4	Hco3	Co3	No3	F	SAR	TA	TH
Re - 86	1004	7.2	643	4.69	70	11	127	4.4	0.745	81.7	101	305	Nil	35	0.42	3.7	180	221
Re - 87	1033	7.2	661	2.59	80	4.8	133	4.7	0.65	89	106	305	Nil	36	0.52	3.9	180	221
Re - 88	1024	7.2	655	5.23	76	16	115	4.7	0.666	85	106	305	Nil	34	0.63	3.1	200	261
Re - 89	1091	7.4	698	5.74	40	38	129	5.5	0.756	114	96	305	Nil	41	0.691	3.5	200	260
Re - 90	1529	7.2	979	3.05	100	18	200	2.973	0.19	185	91	488	Nil	10	0.53	4.8	160	326
Re - 91	1388	7.3	888	4.67	70	20	198	1.5	0.91	163	134	366	Nil	28	0.63	5.3	180	259
Re - 92	1288	7.7	824	5.2	48	28	186	3.3	0.6	146	120	366	Nil	11.4	0.46	5.3	160	238
Re - 93	1226	7.1	785	4.83	90	13	152	2	0.582	153	82	366	Nil	15	0.44	3.9	180	280
Re - 94	2005	6.9	1283	4.17	154	15.6	251	3.2	1.019	298	120	549	Nil	8	0.46	5.1	220	451
Re - 95	1365	7.1	874	3.14	50	30	198	1.41	0.6	149	48	488	Nil	26	0.67	5.4	220	251
Re - 96	1940	7.4	1242	4.7	46	50	294	2.301	0.941	213	101	671	Nil	15	0.9	7.2	320	321
Re - 97	1069	7.1	684	4.89	80	17	129	1.72	0.784	85	96	366	Nil	17	0.42	3.5	180	402
Re - 98	1523	7	975		102	19	196	0.9	0.784	178	101	488	Nil	6.3	0.44	4.7	240	331
Re - 99	1183	7.2	757	4.6	100	12	133	1.21	0.711	142	82	366	Nil	6.6	0.45	3.4	220	396
Re - 100	1012	7.1	648	5.04	66	22	113	3.2	0.795	71	53	415	Nil	12.5	0.35	3.1	240	257

Annex IV :Quality of the analysis

Sample No.	Method1			Method 2			Method 3		
	Cations	Anions	Error %	Calculate EC	Measured EC	Deviation %	Calculate TDS	Measured TDS	Ratio
ZA-1	12.8	12.8	0.2	1279.6	1283.0	0.1	768.9	821.0	1.1
ZA-2	10.3	10.4	0.2	1035.5	1038.0	0.1	606.4	664.0	1.1
ZA-3	12.9	13.0	0.4	1294.4	1298.0	0.1	751.1	831.0	1.1
ZA-4	9.8	9.9	0.1	984.8	986.0	0.1	587.9	631.0	1.1
ZA-5	9.5	9.5	-0.1	953.5	956.0	0.1	546.1	612.0	1.1
ZA-6	10.3	10.2	-0.4	1026.1	1026.0	0.0	587.4	657.0	1.1
ZA-7	9.8	9.9	0.1	984.6	985.0	0.0	593.0	630.0	1.1
ZA-8	9.8	9.8	0.0	981.4	981.0	0.0	583.3	628.0	1.1
ZA-9	13.7	13.7	-0.1	1368.1	1374.0	0.2	817.4	879.0	1.1
ZA-10	13.0	13.1	0.3	1309.0	1314.0	0.2	790.7	841.0	1.1
ZA-11	11.3	11.3	0.1	1131.3	1133.0	0.1	672.7	725.0	1.1
ZA-12	10.3	10.3	0.0	1027.4	1207.0	8.0	612.7	657.0	1.1
ZA-13	9.2	9.2	-0.2	919.3	921.0	0.1	562.5	589.0	1.0
ZA-14	10.0	10.1	0.4	1002.8	1008.0	0.3	581.8	645.0	1.1
ZA-15	10.3	10.3	-0.1	1031.1	1029.0	-0.1	608.5	659.0	1.1
ZA-16	12.9	12.9	0.0	1286.2	1291.0	0.2	773.8	826.0	1.1

ZA-17	12.8	12.9	0.2	1282.7	1286.0	0.1	772.1	823.0	1.1
ZA-18	15.5	15.6	0.2	1551.4	1553.0	0.1	909.0	994.0	1.1
ZA-19	10.0	10.1	0.4	1007.9	1012.0	0.2	592.9	648.0	1.1
ZA-20	17.7	17.7	0.0	1767.1	1766.0	0.0	1063.7	1130.0	1.1
ZA-21	18.5	18.6	0.1	1855.8	1860.0	0.1	1110.5	1190.0	1.1
ZA-22	20.7	20.7	-0.1	2070.8	2070.0	0.0	1235.5	1325.0	1.1
ZA-23	26.4	26.4	0.1	2640.2	2640.0	0.0	1546.3	1690.0	1.1
ZA-24	85.3	85.4	0.0	8533.8	8540.0	0.0	5008.7	5466.0	1.1
ZA-25	31.4	31.4	0.1	3138.6	3140.0	0.0	1878.5	2010.0	1.1
ZA-26	13.2	13.2	0.0	1322.1	1323.0	0.0	795.3	847.0	1.1
ZA-27	13.2	13.2	0.0	1322.1	1323.0	0.0	795.3	847.0	1.1
ZA-28	9.1	9.1	-0.1	908.9	908.0	0.0	544.2	581.0	1.1
ZA-29	18.5	18.4	-0.2	1842.0	1840.0	-0.1	1086.8	1178.0	1.1
ZA-30	13.8	13.8	0.1	1376.5	1376.0	0.0	815.4	881.0	1.1
ZA-31	11.9	12.0	0.3	1195.4	1198.0	0.1	716.1	767.0	1.1
ZA-32	40.1	40.1	-0.1	4009.3	4010.0	0.0	2404.4	2566.0	1.1
ZA-33	10.5	10.4	-0.1	1044.1	1042.0	-0.1	637.9	667.0	1.0
ZA-34	9.5	9.6	0.4	952.4	954.0	0.1	566.7	611.0	1.1
ZA-35	16.6	16.6	-0.1	1660.5	1663.0	0.1	994.2	1064.0	1.1
ZA-36	17.1	17.1	0.1	1708.6	1706.0	-0.1	1018.7	1092.0	1.1
ZA-37	9.3	9.3	0.5	930.7	932.0	0.1	544.6	597.0	1.1
ZA-38	11.4	11.4	-0.1	1137.4	1142.0	0.2	665.4	731.0	1.1
ZA-39	16.6	16.6	0.0	1657.2	1659.0	0.1	1010.9	1062.0	1.1

ZA-40	10.0	10.1	0.6	1003.0	1002.0	0.0	587.0	641.0	1.1
ZA-41	19.9	19.8	-0.1	1984.3	1980.0	-0.1	1162.4	1267.0	1.1
ZA-42	9.9	9.9	-0.1	987.4	987.0	0.0	585.2	632.0	1.1
ZA-43	9.5	9.5	0.0	947.8	948.0	0.0	563.4	607.0	1.1
ZA-44	10.8	10.8	0.1	1081.0	1081.0	0.0	639.0	692.0	1.1
ZA-45	11.3	11.2	-0.3	1128.0	1125.0	-0.1	652.2	720.0	1.1
ZA-46	90.4	90.4	0.0	9040.0	9040.0	0.0	5225.7	5786.0	1.1
ZA-47	57.5	57.5	0.0	5748.7	5750.0	0.0	3030.8	3680.0	1.2
ZA-48	13.6	13.6	0.0	1362.6	1361.0	-0.1	805.3	871.0	1.1
ZA-49	13.7	13.7	0.0	1369.4	1368.0	-0.1	813.5	876.0	1.1
ZA-50	20.0	20.0	0.1	1997.2	2000.0	0.1	1182.9	1280.0	1.1
ZA-51	26.6	26.7	0.2	2666.2	2670.0	0.1	1583.7	1709.0	1.1
ZA-52	10.8	10.8	-0.1	1080.6	1078.0	-0.1	626.8	690.0	1.1
ZA-53	10.3	10.3	0.0	1030.0	1031.0	0.0	617.5	660.0	1.1
ZA-54	13.5	13.5	0.1	1347.4	1350.0	0.1	791.5	864.0	1.1
ZA-55	12.6	12.6	0.1	1260.2	1256.0	-0.2	740.7	804.0	1.1
ZA-56	12.0	12.1	0.4	1202.2	1208.0	0.2	689.5	773.0	1.1
ZA-57	11.8	11.8	0.0	1181.5	1181.0	0.0	682.5	756.0	1.1
ZA-58	17.8	17.8	0.0	1783.8	1781.0	-0.1	1044.6	1140.0	1.1
ZA-59	10.7	10.6	-0.3	1063.3	1061.0	-0.1	610.1	679.0	1.1
ZA-60	11.6	11.6	0.1	1160.5	1161.0	0.0	699.2	743.0	1.1
ZA-61	11.1	11.3	0.6	1120.4	1124.0	0.2	664.5	719.0	1.1
ZA-62	18.0	18.0	0.1	1799.6	1803.0	0.1	1020.1	1154.0	1.1

ZA-63	11.1	11.1	0.1	1107.5	1110.0	0.1	665.2	710.0	1.1
ZA-64	19.4	19.3	-0.2	1937.7	1937.0	0.0	1111.0	1240.0	1.1
ZA-65	12.6	12.7	0.2	1262.8	1265.0	0.1	748.6	810.0	1.1
ZA-66	8.8	8.8	0.1	879.2	881.0	0.1	532.3	564.0	1.1
ZA-67	9.6	9.7	0.2	965.4	964.0	-0.1	581.8	617.0	1.1
ZA-68	14.9	14.9	-0.1	1486.8	1489.0	0.1	880.7	953.0	1.1
ZA-69	12.0	11.9	-0.2	1196.8	1201.0	0.2	725.1	769.0	1.1
ZA-70	14.7	14.7	0.0	1471.4	1472.0	0.0	857.0	942.0	1.1
ZA-71	14.7	14.8	0.1	1474.3	1474.0	0.0	884.7	943.0	1.1
ZA-72	14.8	14.9	0.2	1485.2	1486.0	0.0	882.5	951.0	1.1
ZA-73	13.7	13.8	0.1	1373.5	1372.0	-0.1	821.8	878.0	1.1
ZA-74	13.7	13.7	0.1	1371.7	1371.0	0.0	825.9	877.0	1.1
ZA-75	13.2	13.2	-0.3	1320.7	1320.0	0.0	793.3	845.0	1.1
ZA-76	18.3	18.3	0.0	1830.2	1831.0	0.0	1089.8	1172.0	1.1
ZA-77	18.2	18.1	-0.1	1813.7	1813.0	0.0	1062.5	1160.0	1.1
ZA-78	12.3	12.3	0.0	1231.9	1231.0	0.0	737.4	788.0	1.1
ZA-79	10.3	10.3	0.0	1031.1	1033.0	0.1	615.3	661.0	1.1
ZA-80	12.9	13.0	0.3	1294.5	1297.0	0.1	771.2	831.0	1.1
ZA-81	13.4	13.4	-0.2	1342.1	1340.0	-0.1	792.2	858.0	1.1
ZA-82	14.5	14.4	0.0	1445.4	1445.0	0.0	865.0	925.0	1.1
ZA-83	12.1	12.1	0.2	1208.8	1210.0	0.0	728.1	774.0	1.1
ZA-84	14.8	14.9	0.3	1483.0	1489.0	0.2	890.5	953.0	1.1
ZA-85	11.1	11.1	0.2	1109.3	1112.0	0.1	659.6	712.0	1.1

ZA-86	12.0	12.0	-0.3	1201.5	1203.0	0.1	707.8	770.0	1.1
ZA-87	27.0	27.0	0.0	2699.2	2700.0	0.0	1628.4	1728.0	1.1
ZA-88	18.0	18.0	0.2	1801.1	1800.0	0.0	1091.4	1152.0	1.1
ZA-89	18.2	18.3	0.0	1825.2	1829.0	0.1	1092.4	1171.0	1.1
ZA-90	18.2	18.3	0.2	1826.6	1829.0	0.1	1107.6	1171.0	1.1
ZA-91	18.7	18.6	-0.1	1863.3	1865.0	0.0	1113.3	1194.0	1.1
ZA-92	13.7	13.7	0.0	1368.5	1367.0	-0.1	819.1	875.0	1.1
ZA-93	10.3	10.4	0.3	1038.0	1043.0	0.2	623.1	668.0	1.1
ZA-94	10.1	10.2	0.2	1015.1	1016.0	0.0	612.4	650.0	1.1
ZA-95	10.6	10.6	-0.1	1060.0	1058.0	-0.1	626.2	677.0	1.1
ZA-96	9.3	9.3	0.0	926.4	926.0	0.0	539.8	593.0	1.1
ZA-97	12.8	12.8	0.1	1277.0	1277.0	0.0	748.6	817.0	1.1
ZA-98	13.7	13.7	0.0	1368.0	1367.0	0.0	802.6	875.0	1.1
ZA-99	10.6	10.7	0.3	1065.3	1067.0	0.1	618.1	683.0	1.1
ZA-100	12.5	12.6	0.3	1255.1	1257.0	0.1	721.0	805.0	1.1
ZA-101	12.5	12.6	0.2	1255.0	1256.0	0.0	732.4	804.0	1.1
ZA-102	13.1	13.0	-0.2	1305.7	1303.0	-0.1	767.6	834.0	1.1
ZA-103	10.7	10.7	0.3	1069.7	1072.0	0.1	614.3	686.0	1.1
ZA-104	13.0	13.1	0.2	1308.1	1310.0	0.1	767.7	838.0	1.1
ZA-105	10.7	10.7	-0.2	1072.0	1071.0	0.0	627.6	685.0	1.1
ZA-106	11.9	11.9	0.1	1189.2	1190.0	0.0	688.0	762.0	1.1
ZA-107	11.4	11.4	0.3	1139.9	1143.0	0.1	664.0	732.0	1.1
ZA-108	10.1	10.1	0.0	1007.6	1009.0	0.1	593.5	646.0	1.1

ZA-109	13.2	13.2	0.3	1320.0	1324.0	0.2	775.3	847.4	1.1
ZA-110	11.5	11.5	0.1	1147.2	1149.0	0.1	669.9	735.0	1.1
ZA-111	12.0	12.0	0.1	1199.3	1200.0	0.0	691.5	768.0	1.1
ZA-112	12.4	12.5	0.3	1246.1	1248.0	0.1	723.4	799.0	1.1
ZA-113	13.6	13.6	-0.1	1357.5	1357.0	0.0	787.0	869.0	1.1
ZA-114	12.7	12.8	0.1	1275.8	1277.0	0.0	756.8	817.0	1.1
ZA-115	156.1	156.1	0.0	15610.3	15610.0	0.0	9582.8	9990.0	1.0
ZA-116	19.5	19.6	0.2	1951.7	1955.0	0.1	1197.7	1251.0	1.0
ZA-117	21.6	21.6	0.0	2160.4	2160.0	0.0	1288.3	1382.0	1.1
ZA-118	17.2	17.2	0.1	1723.8	1724.0	0.0	1035.8	1103.4	1.1
ZA-119	16.9	16.9	0.0	1691.4	1691.0	0.0	989.5	1082.0	1.1
ZA-120	23.1	23.1	0.0	2308.7	2310.0	0.0	1332.0	1478.0	1.1
ZA-121	22.1	22.1	0.0	2209.2	2210.0	0.0	1274.9	1414.0	1.1
ZA-122	17.2	17.3	0.2	1727.8	1731.0	0.1	988.2	1108.0	1.1
ZA-123	9.9	9.9	0.1	991.8	995.0	0.2	587.5	637.0	1.1
ZA-124	13.4	13.4	0.2	1341.1	1342.0	0.0	790.6	859.0	1.1
ZA-125	10.1	10.2	0.3	1012.3	1014.0	0.1	590.1	649.0	1.1
ZA-126	9.7	9.6	-0.2	964.3	963.0	-0.1	574.0	616.0	1.1
ZA-127	13.4	13.4	0.1	1342.5	1342.0	0.0	787.7	859.0	1.1
ZA-128	11.8	11.8	0.0	1182.5	1183.0	0.0	686.0	757.0	1.1
ZA-129	14.8	14.9	0.1	1483.6	1482.0	-0.1	849.5	949.0	1.1

Sample No.	Method1			Method 2			Method 3		
	Cations	Anions	Error %	Calculate EC	Measured EC	Deviation %	Calculate TDS	Measured TDS	Ratio
Re - 01	11.5	11.42	-0.2	1144	1144	0.00	669	732	1.09
Re - 02	9.7	9.73	0.2	972	972	0.02	560	622	1.11
Re - 03	10.2	10.29	0.2	1027	1033	0.30	617	661	1.07
Re - 04	10.1	10.09	0.1	1008	1011	0.15	638	647	1.01
Re - 05	11.0	10.97	0.0	1097	1099	0.09	616	703	1.14
Re - 06	12.3	12.26	-0.3	1229	1229	0.00	773	787	1.02
Re - 07	12.2	12.22	0.1	1221	1222	0.04	760	782	1.03
Re - 08	9.2	8.68	-2.7	892	917	1.39	507	587	1.16
Re - 09	9.0	9.01	0.2	899	905	0.33	549	579	1.06
Re - 10	10.5	10.51	0.1	1050	1053	0.12	640	674	1.05
Re - 11	10.0	9.96	-0.2	998	998	0.02	618	639	1.03
Re - 12	9.5	9.63	0.5	959	961	0.12	576	615	1.07
Re - 13	9.7	9.78	0.4	974	977	0.14	604	625	1.03
Re - 14	18.3	18.32	0.0	1833	1838	0.14	1124	1176	1.05
Re - 15	10.3	10.40	0.6	1034	1038	0.22	646	664	1.03
Re - 16	15.3	15.31	0.0	1530	1529	-0.04	919	979	1.07
Re - 17	11.1	11.03	-0.1	1105	1105	0.02	676	707	1.05

Re - 18	11.4	11.38	-0.2	1141	1137	-0.16	681	728	1.07
Re - 19	13.0	12.96	0.0	1295	1297	0.06	803	830	1.03
Re - 20	10.2	10.23	0.1	1022	1023	0.04	631	655	1.04
Re - 21	10.3	10.47	0.6	1040	1046	0.28	606	669	1.10
Re - 22	9.9	9.98	0.5	993	997	0.20	596	638	1.07
Re - 23	10.1	10.10	0.0	1010	1011	0.03	637	647	1.02
Re - 24	12.9	12.91	0.2	1289	1292	0.11	821	827	1.01
Re - 25	10.0	10.02	-0.1	1002	999	-0.16	625	639	1.02
Re - 26	9.2	9.16	-0.2	918	915	-0.16	564	586	1.04
Re - 27	11.1	11.14	0.0	1114	1112	-0.11	696	712	1.02
Re - 28	12.6	12.06	-2.1	1232	1257	1.01	774	804	1.04
Re - 29	9.2	9.36	0.7	929	933	0.19	575	597	1.04
Re - 30	9.3	10.08	3.9	970	926	-2.30	618	593	0.96
Re - 31	9.9	9.94	0.3	992	993	0.07	614	636	1.04
Re - 32	10.3	10.33	0.1	1032	1031	-0.03	644	660	1.02
Re - 33	17.2	17.19	-0.1	1721	1724	0.08	1122	1103	0.98
Re - 34	12.1	12.19	0.2	1216	1216	0.02	784	778	0.99
Re - 35	16.5	16.48	0.0	1648	1654	0.20	1004	1059	1.05
Re - 36	26.4	26.52	0.2	2646	2650	0.08	1625	1695	1.04
Re - 37	17.7	17.71	0.1	1769	1774	0.15	1123	1135	1.01

Re - 38	13.8	14.84	3.7	1431	1482	1.76	882	949	1.08
Re - 39	12.6	12.61	-0.1	1263	1262	-0.03	806	808	1.00
Re - 40	11.4	11.39	-0.2	1141	1144	0.14	719	732	1.02
Re - 41	10.3	10.46	0.7	1039	1041	0.11	657	666	1.01
Re - 42	11.7	12.16	2.0	1192	1169	-0.96	746	748	1.00
Re - 43	10.3	10.26	-0.2	1028	1029	0.04	631	659	1.04
Re - 44	11.9	11.83	-0.1	1184	1183	-0.06	745	757	1.02
Re - 45	15.4	15.38	0.0	1538	1536	-0.06	978	983	1.01
Re - 46	12.6	12.66	0.3	1262	1263	0.03	789	808	1.02
Re - 47	10.5	10.57	0.2	1055	1056	0.06	638	676	1.06
Re - 48	9.8	9.85	0.0	985	987	0.10	602	632	1.05
Re - 49	9.8	9.73	-0.3	976	975	-0.06	618	624	1.01
Re - 50	13.4	13.35	-0.3	1339	1339	0.00	856	857	1.00
Re - 51	11.9	11.83	-0.3	1186	1185	-0.05	755	758	1.00
Re - 52	11.7	11.64	-0.3	1168	1169	0.06	740	748	1.01
Re - 53	30.0	30.05	0.0	3004	3010	0.10	1797	1926	1.07
Re - 54	33.4	33.39	0.0	3338	3340	0.03	1993	2138	1.07
Re - 55	44.3	44.32	0.0	4431	4430	-0.01	2701	2835	1.05
Re - 56	19.7	19.69	0.0	1969	1970	0.01	1167	1261	1.08
Re - 57	11.9	11.84	-0.3	1187	1189	0.08	743	761	1.02

Re - 58	13.8	13.82	0.3	1379	1377	-0.06	870	881	1.01
Re - 59	10.6	10.59	-0.1	1060	1059	-0.05	644	678	1.05
Re - 60	17.7	17.70	0.0	1769	1770	0.02	1121	1133	1.01
Re - 61	11.4	11.42	0.0	1141	1140	-0.06	684	730	1.07
Re - 62	15.1	15.09	-0.1	1511	1510	-0.03	928	966	1.04
Re - 63	9.4	9.35	-0.1	936	931	-0.28	552	596	1.08
Re - 64	18.2	18.20	-0.1	1821	1820	-0.03	1134	1165	1.03
Re - 65	99.8	100.41	0.3	10010	10040	0.15	6764	6426	0.95
Re - 66	26.3	26.30	0.0	2631	2630	-0.03	1650	1683	1.02
Re - 67	15.9	15.91	-0.1	1592	1589	-0.09	963	1017	1.06
Re - 68	18.3	18.37	0.1	1836	1830	-0.15	1102	1171	1.06
Re - 69	13.9	13.90	-0.1	1392	1390	-0.07	877	890	1.02
Re - 70	27.6	27.62	0.0	2762	2760	-0.04	1698	1766	1.04
Re - 71	20.2	20.21	0.0	2020	2020	-0.01	1246	1293	1.04
Re - 72	34.6	34.63	0.1	3461	3460	-0.01	2428	2214	0.91
Re - 73	23.6	23.58	-0.1	2360	2360	0.00	1473	1510	1.03
Re - 74	9.9	9.89	0.0	989	989	-0.01	602	633	1.05
Re - 75	8.5	8.52	0.2	850	846	-0.24	514	541	1.05
Re - 76	15.6	15.63	0.1	1561	1560	-0.02	1022	998	0.98
Re - 77	9.8	9.83	0.0	983	981	-0.09	598	628	1.05

Re - 78	12.0	12.01	0.0	1201	1200	-0.03	724	768	1.06
Re - 79	16.2	16.17	0.0	1616	1616	-0.01	989	1034	1.05
Re - 80	25.7	25.59	-0.2	2563	2560	-0.06	1551	1638	1.06
Re - 81	12.9	12.91	0.1	1290	1289	-0.05	833	825	0.99
Re - 82	10.5	10.48	0.0	1048	1047	-0.07	648	670	1.03
Re - 83	12.0	11.98	0.1	1197	1200	0.11	763	768	1.01
Re - 84	10.3	10.30	-0.1	1031	1034	0.14	660	662	1.00
Re - 85	11.2	11.08	-0.3	1111	1115	0.16	709	714	1.01
Re - 86	10.1	9.99	-0.4	1003	1004	0.06	649	643	0.99
Re - 87	10.3	10.32	0.0	1032	1033	0.05	674	661	0.98
Re - 88	10.3	10.18	-0.4	1022	1024	0.07	655	655	1.00
Re - 89	10.9	10.91	-0.1	1092	1091	-0.04	689	698	1.01
Re - 90	15.3	15.30	0.1	1529	1529	0.01	910	979	1.08
Re - 91	13.8	13.87	0.1	1385	1388	0.11	864	888	1.03
Re - 92	12.9	12.82	-0.4	1287	1288	0.05	775	824	1.06
Re - 93	12.3	12.28	0.1	1227	1226	-0.03	743	785	1.06
Re - 94	20.0	20.05	0.1	2003	2005	0.05	1189	1283	1.08
Re - 95	13.7	13.65	0.0	1365	1365	-0.01	822	874	1.06
Re - 96	19.3	19.39	0.2	1936	1940	0.11	1141	1242	1.09
Re - 97	11.1	10.69	-1.7	1088	1069	-0.88	663	684	1.03

Re - 98	15.2	15.24	0.0	1524	1523	-0.04	904	975	1.08
Re - 99	11.8	11.84	0.1	1183	1183	-0.01	704	757	1.08
Re - 100	10.1	10.13	-0.1	1014	1012	-0.07	603	648	1.07