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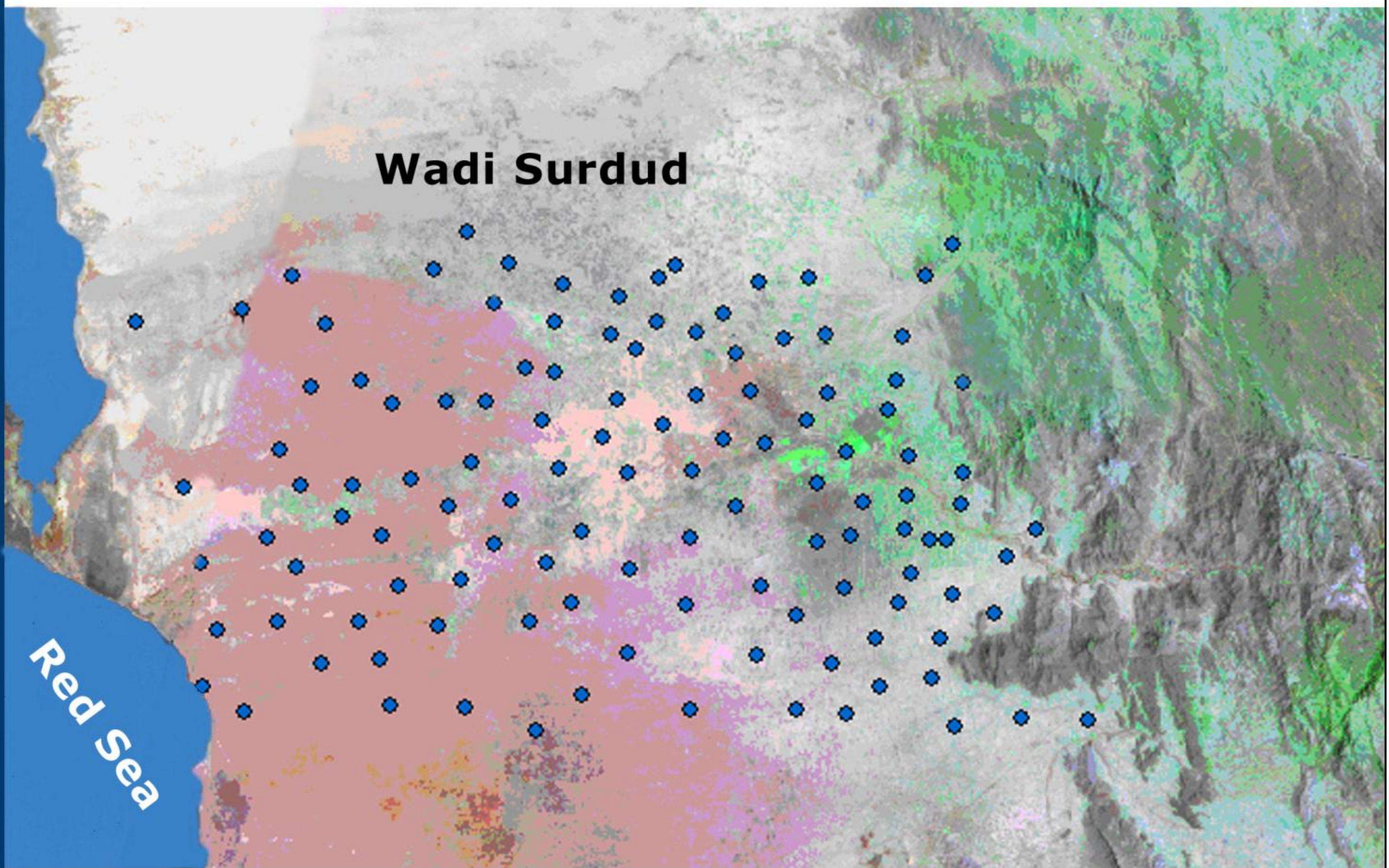
National Water Resources Authority

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

TIHAMA WATER RESOURCES MANAGEMENT

WADI SURDUD Water Quality

Final Report



Sana'a March 2009

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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 Wadi Surdud 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.

Wadi Surdud suffers from over exploitation as well as mismanagement of the water resources in the Wadi. According to the last well inventory for Wadi Surdud which achieved by NWRA in 2008, there are about 3279 operational water points in the Wadi, the total abstraction from these wells are 394,378,289 m3. The over exploitation in the Wadi causes to deterioration of the water quality in the Wadi and especially in the down stream.

So far no detailed systematic study on groundwater quality and its uses has been conducted in Wadi Surdud, but there are many reports which refer to the water quality in the area with respect to physical properties for water such as electrical conductivity, pH and water temperature. Some studies collected few groundwater samples (12 samples) from Wadi Surdud and analysed in the laboratory of NWSA at Sana'a. This work was implemented by YOMINCO – DOH in cooperation with TNO – DGV under water resources assessment (Wadi Surdud) in 1985.

This study concentrate more detail on groundwater quality, and has collected 121 samples from all project area for evaluation the water resources and in order to facilitate the implementation of the integrated water resources management plans in the Tihamah Basin.in the future.

The area consists of two very distinct geographical zones; the topographical low 'coastal plain zone' that forms part of the Tihama plain and the mountainous 'catchment area' to the east. The western part is composed of a gently sloping zone at low elevation excluding Qumah mountain with elevation 78m a.s.l., while at the east the catchment area is a rugged, strongly dissected by Wadi Surdud's stream network mountainous zone that the elevation reaches over 3000m above sea level. The highest elevation points in the eastern boundary is at 3666m a.s.l. (Jabal An Nabi Shuayb), and it is the highest mountain the Arabian Peninsula.

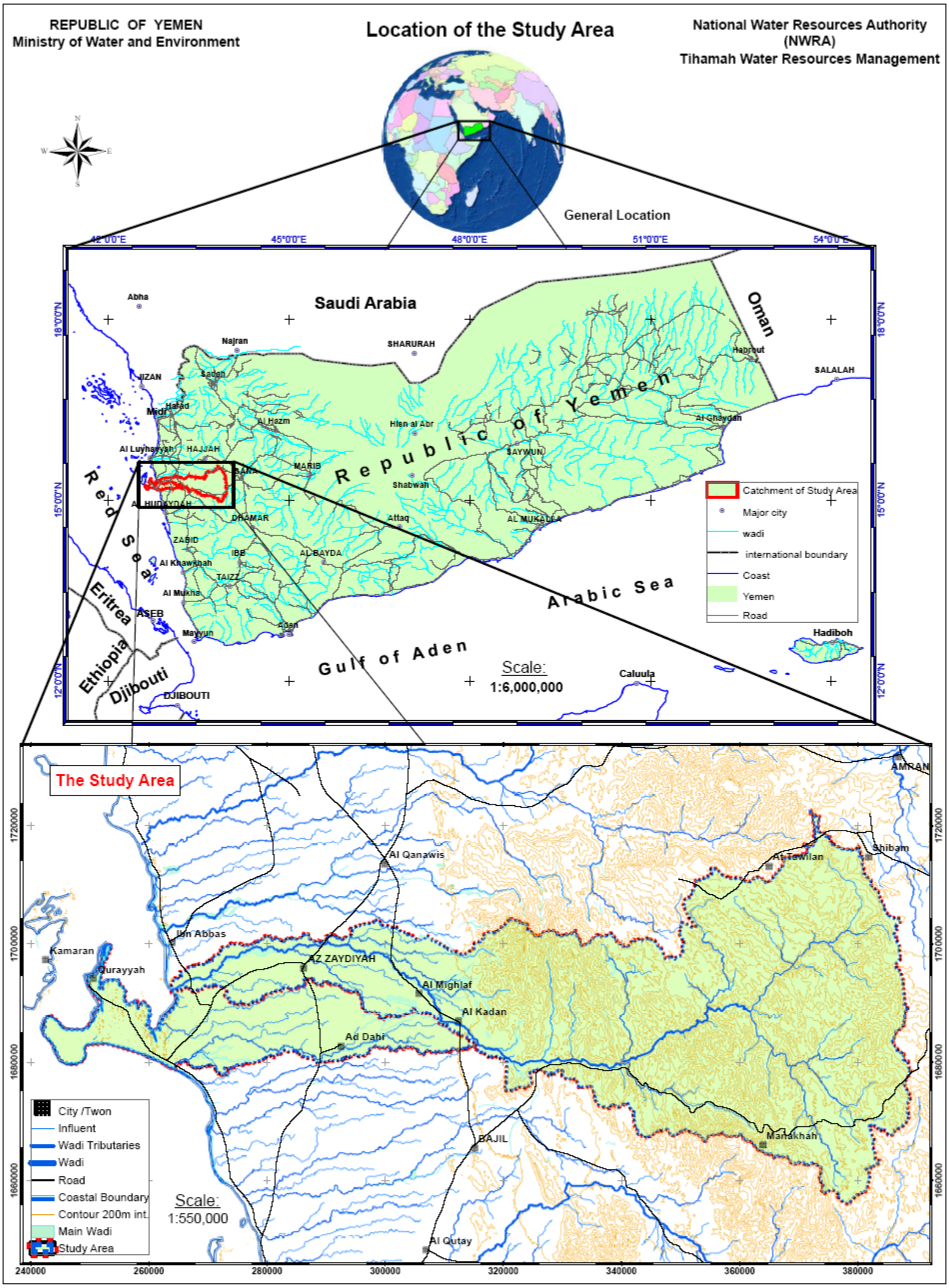
The main tributary of Wadi Surdud is Wadi Ahjur (about 60%) draining mountains in the northeastern boundaries of the catchment area, which is a steep and high sandstone area with an approximately 400 – 500 mm mean annual rainfall. Other tributaries are Wadi Sara, Wadi Yuar and the Wadi channel flowing east of Manakhah, which are relatively small Wadis draining a mountain chain with an approximately 300 mm mean annual rainfall. About 75% of the catchment surface consists of volcanic tuff formations, which are sometimes very steep and sometimes densely cultivated.

The coastal plain area is relatively rich in groundwater; although the mean annual rainfall is low ranges between 50-150 mm, which increases in eastward direction. Mean annual rainfall recorded in the middle of the area at Ad Dahi meteorological station is 138 mm and about 120 mm in Az-Zaideyah in northwest direction of Ad Dahi. The plain receives an important amount of surface water from the catchment area, which feeds the spate-irrigation system and replenishes the extensive groundwater reservoir. The average annual amount of surface water flows is between 50 and 100 million cubic meters. Mean gauged annual amounts until 1991 was 69.3 Mm3. The surface water use is fully dependent on day-to-day stream flows due to lack of storage facilities at present; the existing irrigation distribution system is inefficient, excluding irrigation channels in Al-Kadan area, which irrigate some spate-irrigation areas belonging to ' Surdud Productive State Farm.

1-2 Location

Figure 1 shows the location of the Wadi Surdud, which lies in the middle of the Tihama coastal lain in the west of Yemen. The Wadi Surdud coastal plain lies between longitude 42º 30’ and 43º 20’ East and latitude 15º 00’ and 15º 25’ north. The total area of the project studied (Wadi Surdud coastal plain) - including the Salif Peninsula is 2520 km^2.

Figure 1: Location map for Wadi Surdud



1-3 Population and Economic Activities

The project area includes whole area of Al-Zaideyah, Al-Dhahy, Al-Meghlaf, Al-Munirah, Al-Salif districts and about 80% of rural areas of Bajel district; Bajel town has excluded due to not belonging to the project area. The total population of the project area is about 299,641 according to 'The Final Results of Population, Housing & Establishment Census, 2004'. The urban population is about 20% of the total population of the area. The main towns and urban centers are Al-Zaideyah, Al-Dhahey, Al-Kadan, Al-Munirah, Al-Meghlaf and Al-Salif.

Most of population is involved in agriculture in the coastal plain. About 24,241 ha of the irrigated areas depends mainly on groundwater, while some area debends on spate-irrigated. In the eastern part of the plain, rain-fed agriculture is possible during wet seasons. There are many work vacancies in big farms at local enterprises and investors wages are meagre and payments are about 270-400 Yemeni Reyals daily. Many inhabitants can find seasonal work in harvesting seasons for share crop; sometimes they get 1/8 of the crop harvested.

In addition, a community part of work in grazing, which provide them with a good income from farmers who have some livestock like sheep and goats. Trading in particular livestock is an important in the area because selling them in local markets improves their incomes. Some farmers also sell some livestock to buy fuel for irrigation. The main local bazaar days in the area are Saturday bazaar in Al Meghlaf, Monday in Al Dhahy, Wednesday in Bajel etc.

Some people in the area work in traditional charcoal industry, by collecting wood and burning it under ground to sell it as charcoal to urban people or exporting to other areas.

1-4 Geology and Stratigraphy

A number of surveys and investigation studies were carried out in the past in order to understand the geological features of the area. Some covered the Wadi Surdud area and part zones in the surroundings. The main geological studies carried out in the area are:

- Skipwith (1973) implemented an elaborate review of the red sea and coastal plain of Saudi Arabia.
- Information provided by geological maps (Grolier and Overstreet, 1978; Kruck, 1985).
- Hydrogeological contribution of the Central Tihama made by Kraft et al. (1971).
- Seismic data from Shell and British Petroleum.
- Preliminary data of a regional geo-electrical survey carried out for the Tihama Basin Water Resources Study (Ritsema, 1985).
- Data concerning pre-tertiary formations is provided by (Geukins, 1963 and schulze Theile, 1978).

Water Resources of the Wadi Surdud Area carried out by YOMINCO Department of Hydrology and TNO-DGV (Delft, Netherland) 1984.

After reviewing the above-mentioned studies, the geologic setting of the present Tihama Plain shows that it is completely controlled by the Red Sea Graben, which was formed during the Tertiary period, initiated by fracturing, step faulting and rifting along an anticlinal structure of the African-Arabian shield. The structural and stratigraphic construction of the area is controlled by the tectonic and environment history of the Red Sea Rift System. The Red Sea rift valley is an elongate NNW-SSE basin between the African Continent and the Arabian Peninsula, on both sides separated by faults from the prominent escarpments of the uplifted margins of the Precambrian shields.
The main stratigraphic units are:

Precambrian Basement (PC):
Basement complex of igneous and metamorphic rocks, which are impermeable bedrocks, buried at large depths (2-10 Km) from surface only some outcrops of these rocks in the eastern boundary of the coastal plain. During long periods in the Paleozoic, this metamorphic basement eroded and a Precambrian peneplain was formed.

Paleozoic and Mesozoic sedimentary rocks (P/M):

In Yemen continental sedimentary sequences, like Paleozoic Wajid sandstones, the Triassic-Jurassic Kohlan sandstones, the Cretaceous Tawilah sandstones, and Marine sediments like the Jurassic Amran limestones was found, but in the project area, these rocks are exposed along the eastern margins. They also may be present elsewhere in Tihama at greater depths and hidden by thick sequences of Tertiary and Quaternary deposits. Outcrops of Amran series near the Town of Bajel, some 20 km south of Wadi Surdud can be observed in the eastern margins of the coastal plain.

Cainozoic Tertiary Formation (C):

The thickest serious of sediments overlaying Precambrian basement in the area; the most outstanding and best known formation is the Miocene-evaporite-clastic group. The tertiary formation can be divided into two groups: Tertiary Volcanics (Tv) and Tertiary clastic-evaporites (Baid formation) (Tba).

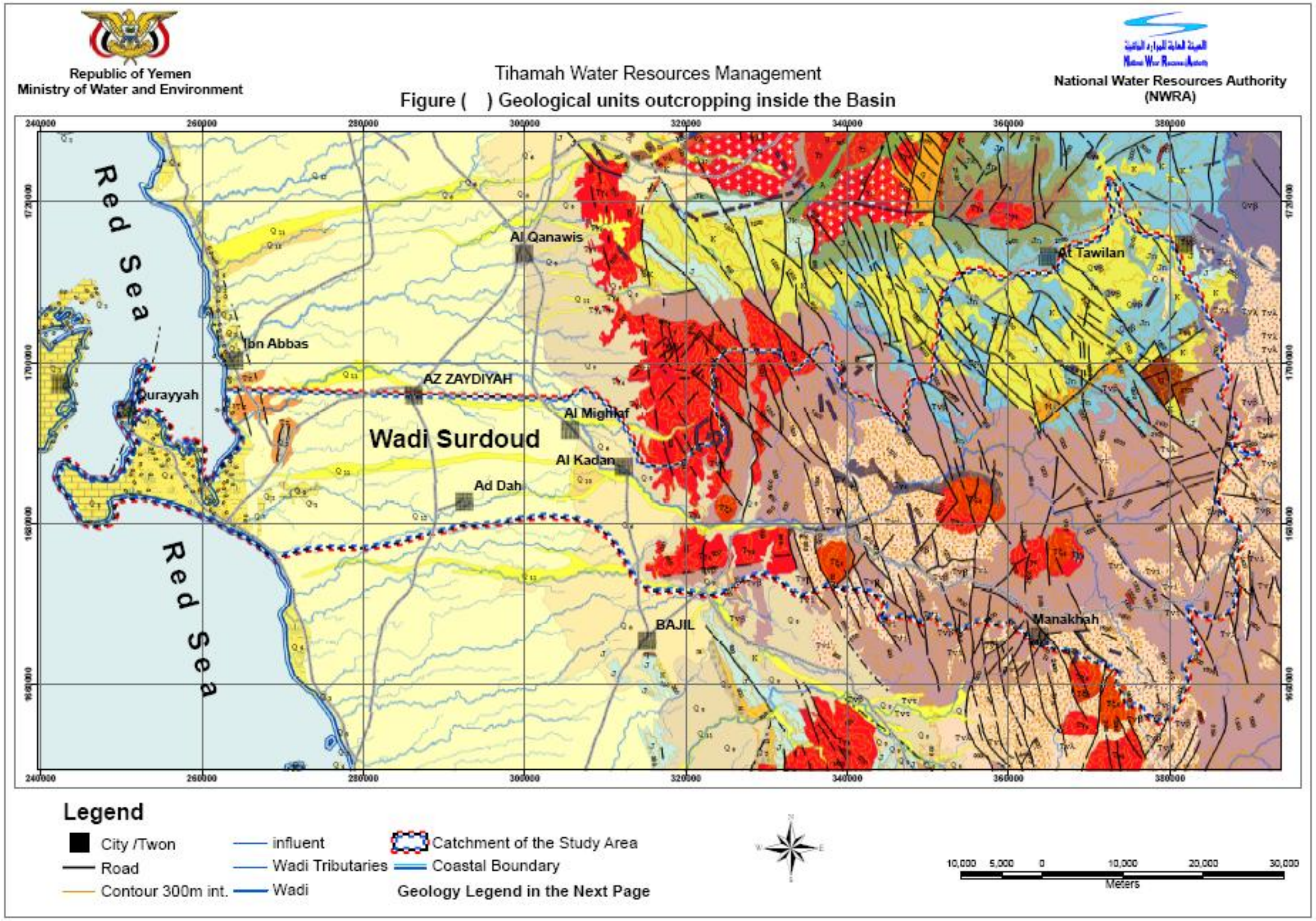
1. **Tertiary Yemen Volcanics (Tv)**; which is silicious shales, tuffs, volcanic flows, sills and intrusives. The lateral extension of the Yemen volcanics in the Tihama plain is not known. Older pre-Miocene volcanics may be present at larger depths; Miocene and younger volcanic flows and pyroclastics likely to be present in the eastern part of Wadi Surdud coastal plain.
2. **Tertiary Baid formation (Tba);** consists of Shales, sandstones, carbonates, anhydrite and halite; all these rocks are of middle-upper Miocene age and considered to be part of the Baid formation. The most famous layer is a rock salt layer occuring at a depth of 2200 m and having thickness of 600 m, forms an uninterrupted monocline, which dips rather steeply to the west (B.P. seismic exploration program); the tertiary rocks exposed in the Wadi Surdud coastal plain at Jabal Qumah as an isolated diapir rock rising up to 78m above sea level. In the center of the diapir rock salt layers exhibit typical vertical flow structures, on the sides younger layers of shales, anhydrites, limestones and sandstones are bended upward by the upwelling and finally out squeezing motion of the salt.

Quaternary Sediments (Q):

Four different types of Quaternary sediments were distinguished by the last geophysical investigations (Van Overmeeren, 1985):

1. Alluvial fan deposits; consists of blocks, boulders, pebbles and sands where Wadi streams dropped their coarser, heavier load upon entering the coastal plain and forming cone-shaped deposits of alluvium. The coarser sediments are found near the eastern margins of the plain and become increasingly finer towards the west. The most recent series are Wadi bed deposits called "alluvial-proluvial" deposits rarely contain clayey material and its thickness from 20m in the east to 40m in central Tihama.
2. Alluvial plain deposits; fluvial deposits of alluvium laid down in streams bed and on flooded plains by braided Wadi streams, which frequently change their coarse. The deposits are badly sorted and range in grain size from boulders and pebbles to sands and clays. Generally, the coarser grains are deposited close to the eastern margins, where the finer ones are transported further downstream. They have thickness of more than 180m. The "alluvial-proluvial" deposits are badly rounded coarse sediments, cemented by clay and including intercalations of carbonate-clay layers. The main difference between this sediments and previous sediments is higher content of fine and clay sediments and higher thickness.
3. Aeolian deposits; fine to medium grained, well sorted sands, transported by wind and deposited as sand plains or forming sand dunes.
4. Recent evaporates; coral blanks and reefal limestones develop off the coast in shallow water. In salt marsh environment (Sabkha) protected by offshore reefs and quiet lagoonal waters, salt precipitate and are mixed with loess and clays. See figure (2.) geological units outcropping in the area.

Figure 2: Geological map of Wadi Surdud



1-5 Hydrogeological Units:

- **Quaternary Aquifer**

The main aquifer in the project area is in quaternary deposits. The fresh groundwater occurs mainly in the pores of the upper unconsolidated strata. Lower and lateral boundaries of the corresponding aquifer system have been identified by geophysical methods (Van Overmeeren, 1985), some drilled wells in the eastern part of the area in Al Kadan, Al Garabeh and boreholes drilled by the WRAY project confirms the picture in the eastern part (Van Overmeeren,1985; Van der Gun, 1985).

The aquifer has been divided into four zones based on hydrogeological conditions, which are:

1. Zone 1: Fresh groundwater occurs mainly in the pores of the upper unconsolidated strata of alluvial boulders, pebbles, gravels, sands and low silt and clay content. This is a good aquifer with medium to high permeability and high productivity in general; the transmisivities range from 500 m^2/d to 2000 m^2/d with an unconfined conditions (Noory Jamal and Jac Van der Gun, 1986); the upper part is unsaturated . Relatively thin 10-50m beds of coarse and permeable sediments overlaying a thick aquitard sequence of older Quaternary deposits at 40-80m below surface. The Quaternary aquifer rests on bedrock and saline tertiary layer is absent in this zone.

2. Zone 2: this zone falls into two distinct units. There are two most probable hypothesis for this dividing (Jac Van der Gun, 1986) are that this boundary is a sharp transition from Alluvial (east) to dominantly Aeolian deposits (west), or, that is a fault or flexure (continuation of ' Jizan flexure') that causes this western part to be thicker (approximately 300m) than the eastern part (200m). The second hypothesis is more probable. This zone in general is a fresh groundwater. There is not much information on the vertical stratification of the delineated aquifer systems. However, a few lithological borehole wells descriptions and geo-electrical sections suggest that upper 20-50m of aquifer system

constitute the aquifer beds overlaying strata of higher clay or silt content considered aquitards and deeper beds of sands considered confined aquifers thickness 5-20m. the lower boundary of the Quaternary aquifer is not well defined yet, perhaps that clay rich or silty Quaternary beds constitute already an effective low permeability lower boundary at depth about 200m in the eastern part and 300m in the western part from the surface.

3. Zone 3: is a fresh to brackish groundwater zone; lithologicaly is a continuation of the Aeolian medium-fine sands layers. Approximately, west of the line Al Munirah – Al Urj fresh groundwater becomes overlain by shallow brackish to saline groundwater.

4. Zone 4: Salt Marshes (Sabkha), with shallow saline groundwater in the low zones near the coast. Water is leaving the aquifer, moves upward through the unsaturated zone and evaporates at the surface and a salt crust is formed.

5. Other Hydrogeological units:
    - Coral reefs aquifer; at the coast, the sandy aquifer interfingers with coral reefs and limestones that contain salt water.
    - Tertiary volcanic and granitic rocks; considered as eastern impermeable boundary that is only dissected by the alluvial fill of Wadi Surdod's narrow valley.
    - Tertiary Baid formation aquifer: large parts of these rocks, if not all, saturated with saline water.
    - Cainozoic and Mesozoic rock units; they are of little practical importance because of their large depths and probably little or no recharge and limestones considered poor aquifer.
    - Main hydrogeological units outcropping in the area shown in figure (1.4.1.).

1-6 Climate

1-6-1 PRECIPITATION

Atmospheric precipitation in the Wadi Surdud area and its upper catchment area comes mainly in the form of rains. Annual rainfall tends to occur mainly during spring and summer rainy seasons however, rainfall may occur during other seasons without large amounts of rainfall. Close to the coast, rainfall is rare and erratic in nature.

Annual rainfall amounts vary from year to year and from location to location in the area. From available information, it is difficult to identify a significant long-term trend due to a low period and missing data for some years of these periods, so there is no well-defined cycle of dry and wet years. The spatial pattern of average annual rainfall over the standard periods (1984-1992) & (2001-2007), which has been chosen due to a complete or nearly complete records are shown in figure (3) and Table (1). The rainfall isohyets map (Figure 4) gives a clear and consistent picture of the spatial pattern of annual rainfall. The western part of the area 'Tihama plain' is the lowest annual rainfall about 120 mm in Zaydiyah rainfall station (TDA) to 140 mm in Ad Dahi Meteorological Station and lower to the west. The mean annual rainfall increases to the east of the plain, it reaches in the lower part of the catchment area in Khamlu rainfall Station 287 mm. By increasing the elevations and direction to eastward mean annual rainfall increases to reach more than 400 mm in Assalf rainfall station with elevation 2250 m a.s.l. in the eastern boarders of the Wadi Surdud catchment area. In Mafhaq and Mayan rainfall stations the mean average rainfall is unclear due to low rainfall amounts in comparison with others stations with lower elevation may be due to the stations areas are surrounding by mountains or technical restrictions. The seasonal pattern general characteristics of the area that there are a well defined rainfall regime, with a first rainy season in spring (March-May) with about 36% of total annual rainfall and a second one in late summer (July-September) with 48% of total annual rainfall. Long periods of dry weather with few or no clouds are common from October to the beginning of spring.

Figure 3: Mean annual rainfall in Wadi Surdud catchment area

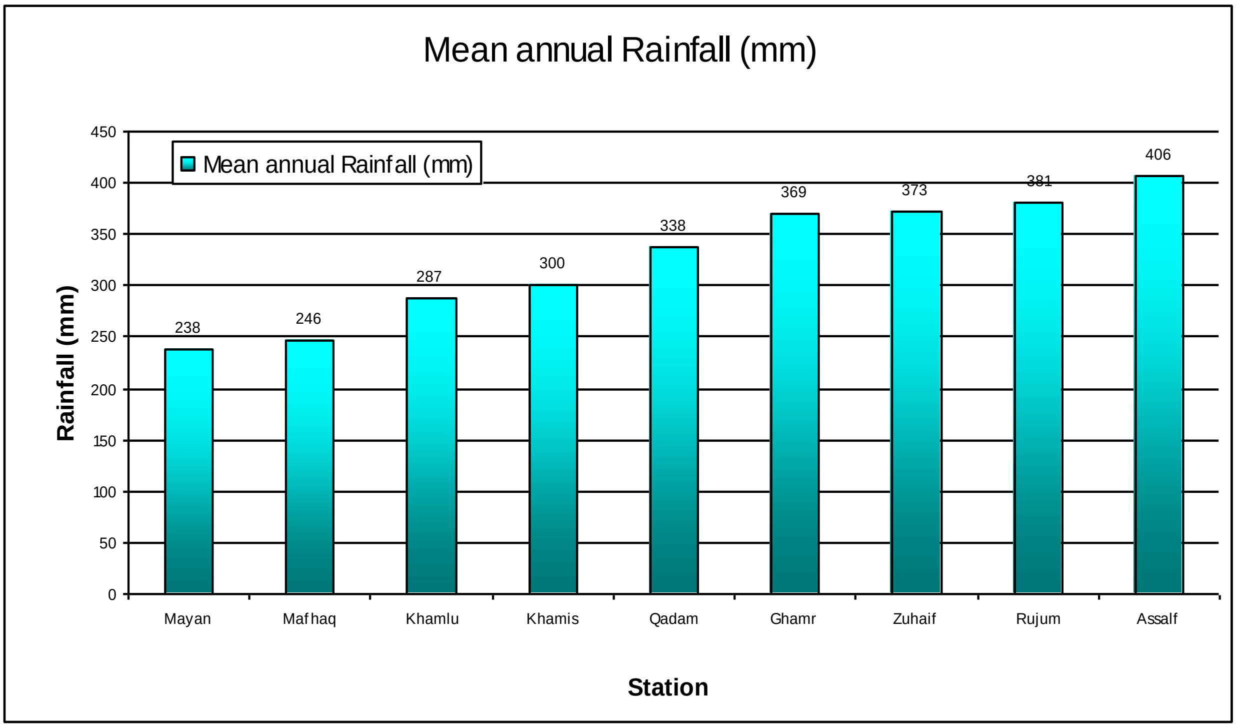
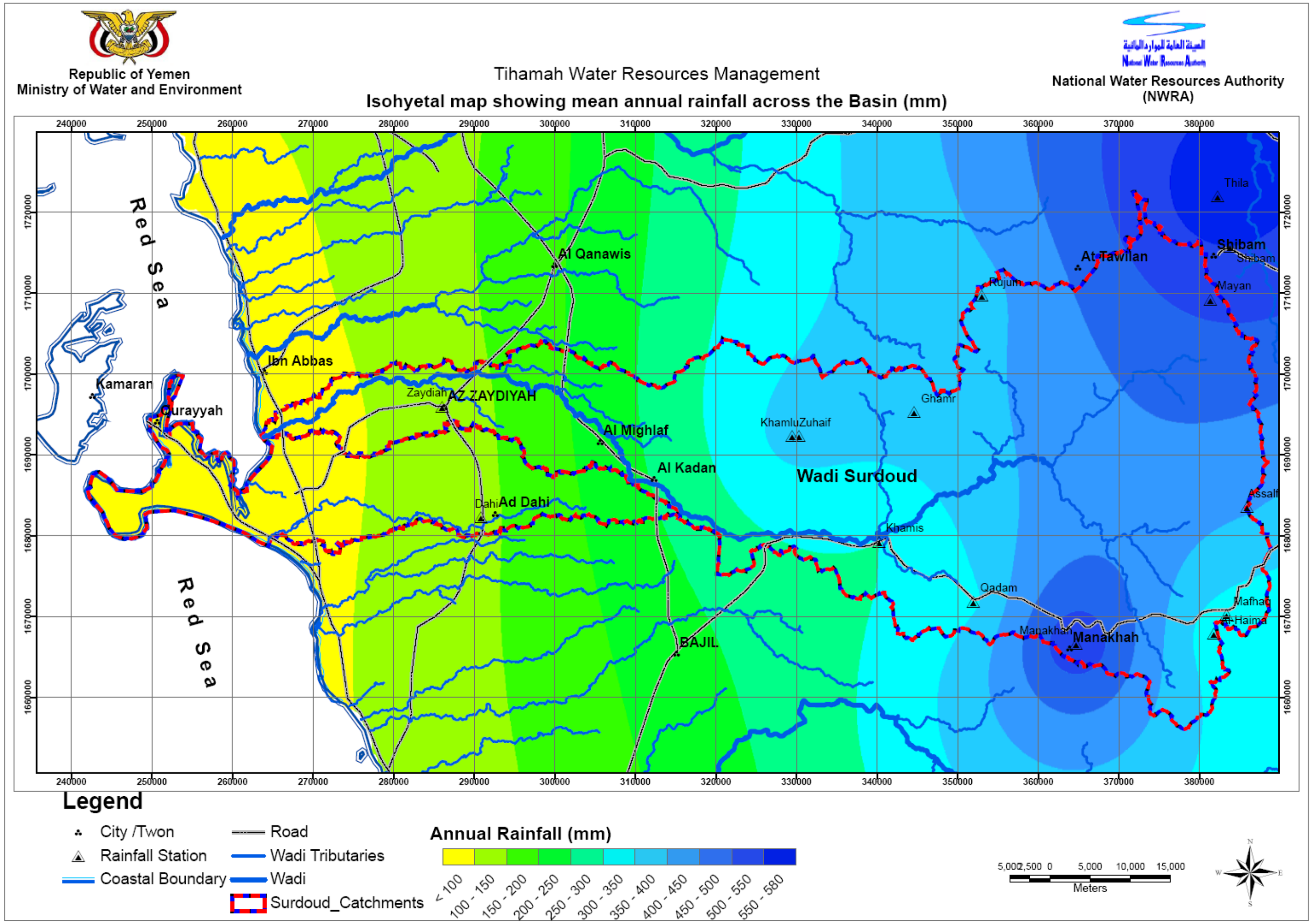


Table 1: Mean Annual rainfall in Wadi Surdud Stations

Station Name	Data period		Average(mm)
	From	To	
Mayan	1984	2006	238
Mafhaq	1984	2007	246
Khamlu	1984	2007	287
Khamis	1984	2007	300
Qadam	1984	2002	338
Ghamr	1984	1992	369
Zuhaif	1984	2007	373
Rujum	1994	2002	381
Assalf	1984	2007	406
average			**326**

Figure 4: The rainfall isohyets map for Wadi Surdud



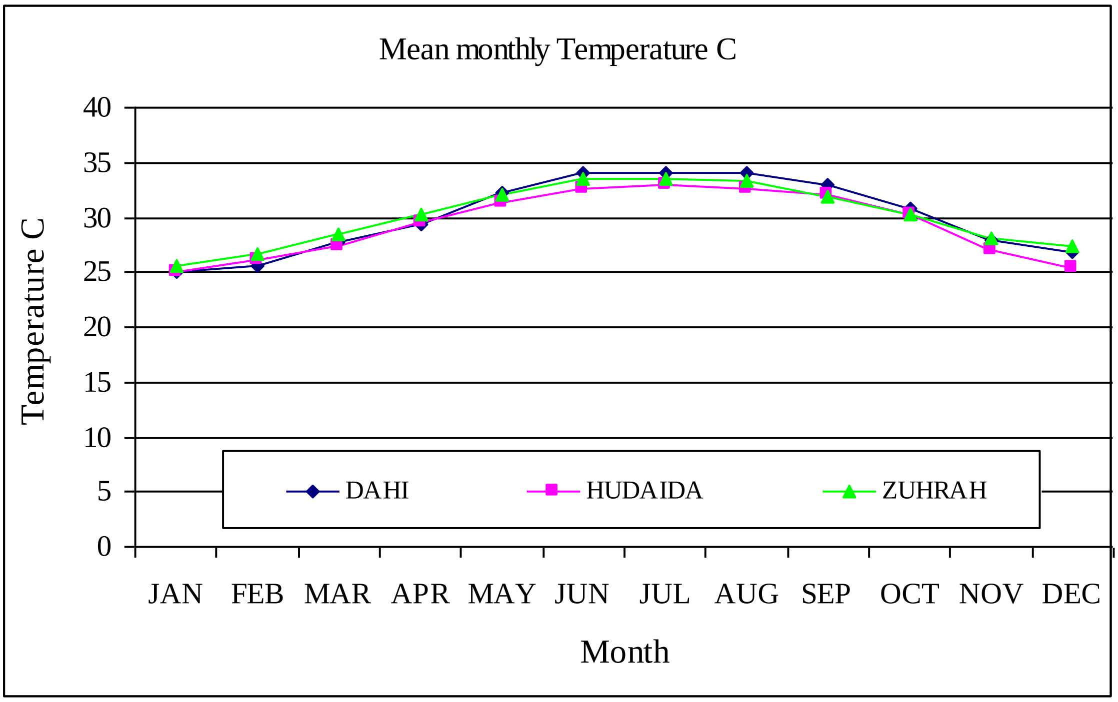
1-6-2 TEMPERATURE

The annual range of temperature variation in the Wadi Surdud coastal plain in the warmest and coolest month of the year is about eight ˚C as recorded in Dahi meteorological station. Table 2 and Fig (5) shows that there is no big difference to the western part of the area towards the sea direction (in Hudaydah meteorological station near coast) due to a slightly solar radiation variation over the territory and to other associated factors, based on data for a period 1984-1991, see appendix IV. The lowest temperature records in Dahi monitoring station is 25 ˚C as average in January and the highest is a little more than 34 ˚C in June month. The highest temperature is always predominantly during summer season (June-September), with a highest average rains in August and September months in Dahi and surrounding areas. The temperature in the mountainous areas to the east (Catchment Area) become lower and lower by increasing elevation.

Table 2:Mean monthly temperature in Wadi Surdud plain (˚C)

Month	DAHI (˚C)	Hudaydah (˚C)	Zuhrah (˚C)
JAN	25.1	25.1	25.6
FEB	25.5	26.1	26.7
MAR	27.7	27.3	28.5
APR	29.3	29.6	30.3
MAY	32.3	31.4	32
JUN	34.1	32.7	33.5
JUL	34	33	33.6
AUG	34	32.6	33.3
SEP	33	32	31.9
OCT	30.9	30.3	30.3
NOV	28	27.1	28.1
DEC	26.8	25.4	27.3

Figure 5:Mean monthly temperature in Wadi Surdud plain



1-6-3 RELATIVE HUMIDITY

Mean monthly relative air humidity in Wadi Surdud coastal plain (middle of the projected area) was recorded ranges between 43 to 65 % depending on temperature and rainy seasons.

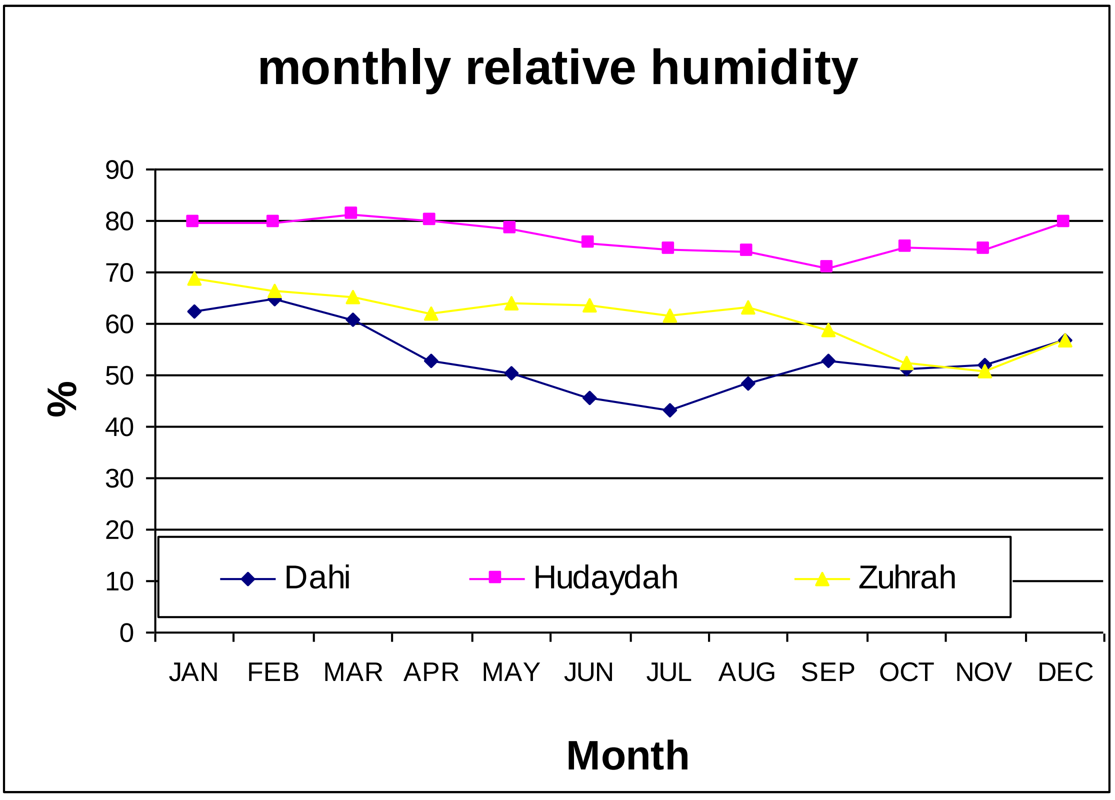
It reaches lowest value is about 43 % in July with highest monthly average temperature 34 °C and increases to about 50 % in August then to about 53 % in September with about 40 and 35 mm of rains respectively. Table 3 & Fig 6 shows monthly average relative humidity for three meteorological stations in the middle of the project area and to the north and the southwest direction of the area.

The average relative humidity increasing to the west direction towards the Red Sea, where it reaches to (70-81 %) in Hudaydah meteorological station.

Table 3:Mean monthly relative humidity in Wadi Surdud plain (%)

Month	DAHI (%)	Hudaydah (%)	Zuhrah (%)
JAN	62.6	79.5	68.8
FEB	64.8	79.8	66.6
MAR	60.7	81.3	65.3
APR	52.9	80.1	62
MAY	50.3	78.3	64
JUN	45.5	75.6	63.8
JUL	43.2	74.4	61.6
AUG	48.4	73.9	63.2
SEP	52.9	70.8	59
OCT	51.1	75	52.5
NOV	51.9	74.4	50.9
DEC	56.8	79.5	56.7

Figure 6:Mean monthly relative humidity in Wadi Surdud plain



2- Hydrochemical Study

2-1. Introduction

This study has been carried out for evaluation the water resources in Wadi Surdud as part of the Integrated water resources management in mid Tihamah Basin. The hydrochemical and groundwater pollution study was completed by the National Water Resources Authority staff with the participation of some the TDA staff and NWRA branch in Hodeidah.

The study has investigated the quality of groundwater resources of Tihamah Basin, and discusses the causes behind their current degradation trends. The study provides useful tools to predict the future outlook water quality in the region. In case measures are not taken to monitor and counteract the contaminating sources, the areas most exposed to critical pollution factors and identified during the study.

2-2 Specific objectives of the study

The specific objectives of the study are summarized as follows:

- Update and obtain information about the hydrogeochemical properties of the main water bearing strata
- Investigate the origin and spatial spread of brackish and saline waters
- Groundwater quality in relation to use
- Check the vulnerability and exposure to pollution

2-3 Work carried out in Wadi Surdud

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

1. Review of the previous hydro- and geo-chemical information
2. Selection of representative water-points for sample collection
3. Specification of the sampling procedures
4. Collection of groundwater samples
5. Analysis in the field and in the laboratory and

6. Data analysis and interpretation as a basis to formulate recommendations

The six activities have been implemented in three sequential stages:

Preparation work (2-3-1)

Field Implementation (2-3-2) and

Analysis & Data Processing (2-3-3)

2-3-1 Preparation work

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

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

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

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

- The water point should be at operational status according to the last well inventory (The results of the well inventory carried out by NWRA for The Wadi was in 2008)
- There is information on pump depth and total depth for water points
- The spatial distribution for samples on the Wadi
- 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

2-3-21. 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 on the laboratory analysis. The team started fieldwork on January 5, 2008 and ended it on February 1,2008 .

2-3-2-2 Sample Collection

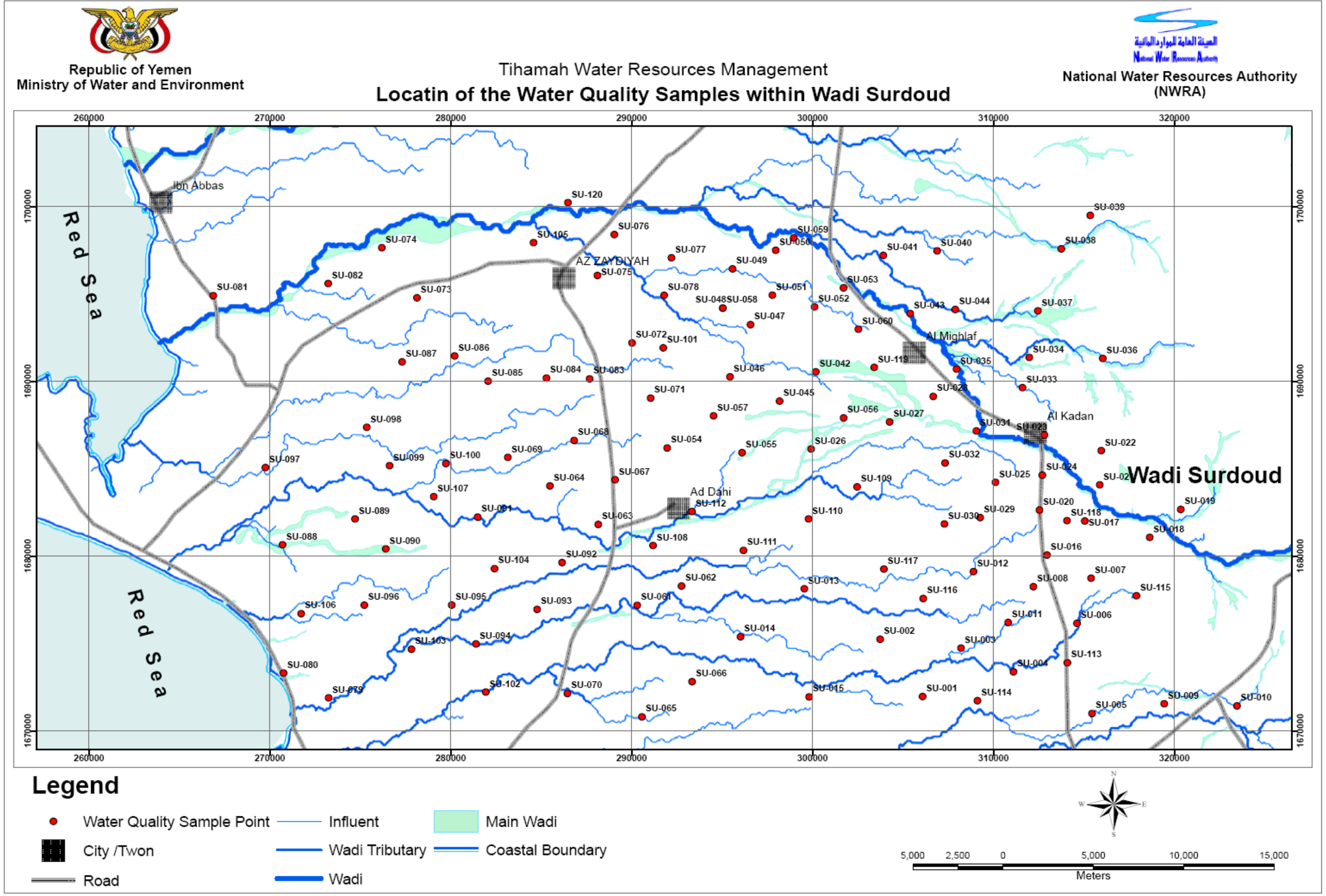
In total, 121 samples were collected from Wadi Surdud (2 samples were duplicates) Annex (II). These wells including 19 dug wells (16%), 37 dug/boreholes (30%) and 64 boreholes (53%). Sample locations and all characteristic are shown in Tables 4 and Figures 7.

Table 4: Types of well water samples collected wells

Well Type	No.	%
Dug	19	16
Borehole	64	53
Dug/Bore	37	30
Spring	1	1
Total	121	100

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.

Figure 7: Well water samples location map



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.

2-3-2-3 Field difficulties

The fieldwork of the water quality study team was hampered by only one difficulty: At the time of the field visit the pumps were out of order. The non operational wells were thus re-visited after repair. This resulted in delay and additional expendition for the study.

2-3-2-4 Measurement of field parameters

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

- **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.

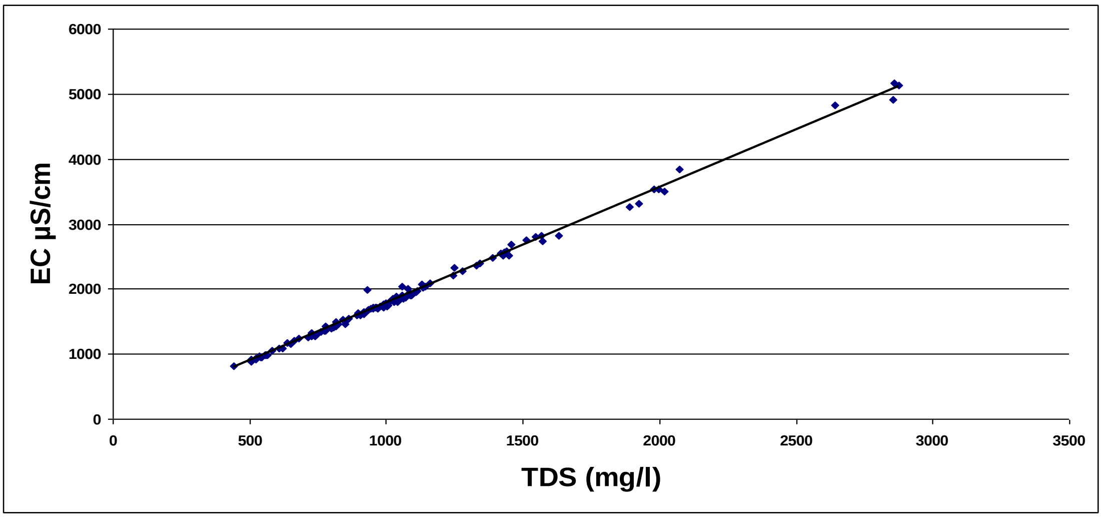
Since the EC and TDS are measurements of the total salt content, they must be directly proportional.

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):

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

Figure 8: The relation between the EC and the TDS values

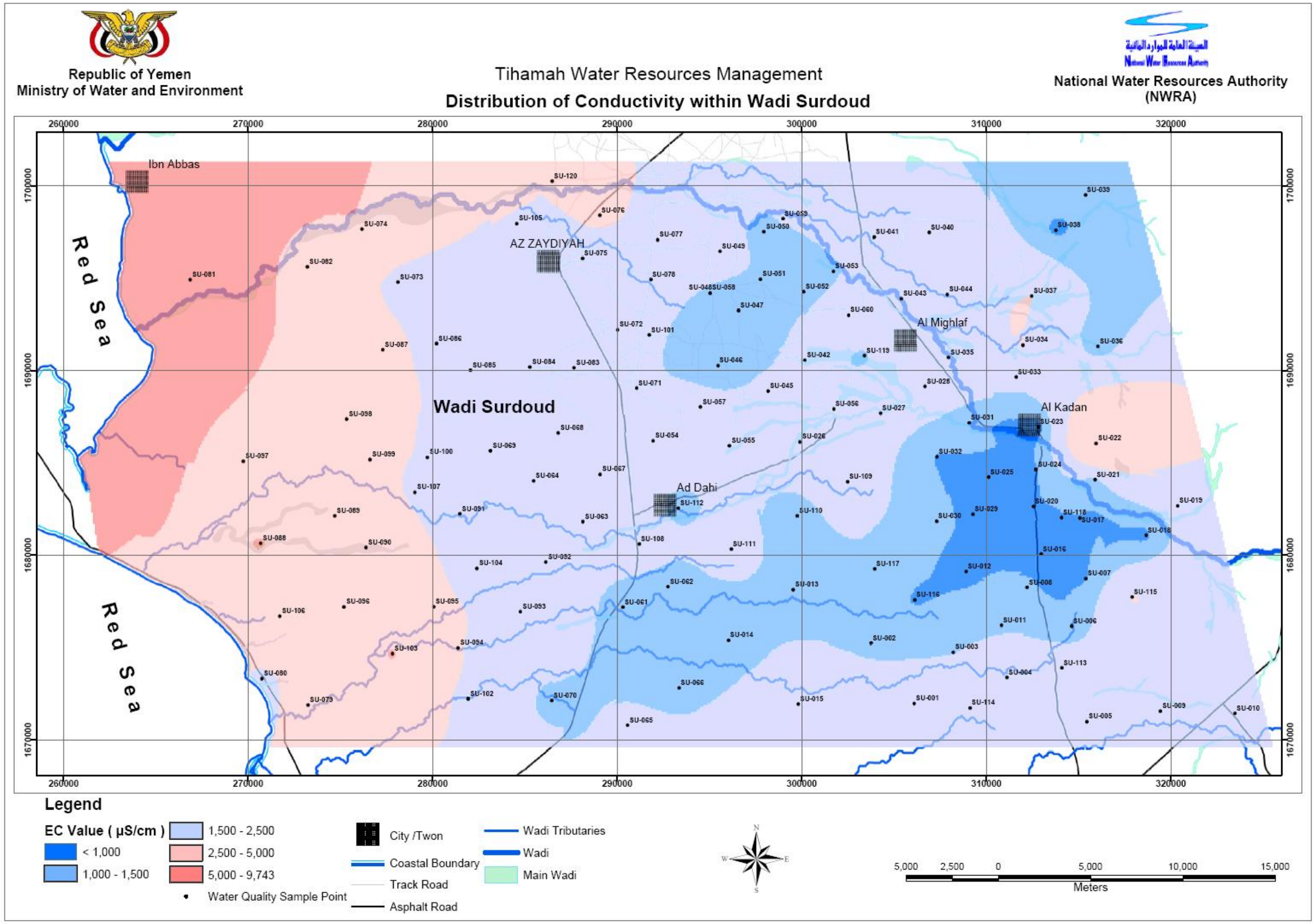


EC varies between 813µS/cm and 9,750 µS/cm in Wadi Surdud with an average of 1947 µS/cm .

Figure 9 clearly illustrates the distribution the concentration of EC values in the area. The general features of the conductivity pattern can by explained rather easily. The conductivity is normal in the upstream with some salinity anomalies area found in Al Zouih to the east of Al Kadan near Bagil town which have high EC reach to more than 4800 µS/cm which due to found sebkha zone, high salinity in the sebkha zone are related to evaporation. The EC increase in the downstream with the direction to the west, it reach to more than 9700 µS/cm in Al Haroneyah Village to the south of Ibn Abbas town. The EC measured during well inventory survey which achieve by NWRA team in 2008 measured in field to about 3360 water points in Wadi Surdud and found that it ranges between 470 µS/cm in the east in Al Jarabeh and Ketabi village, to 18,580 µS/cm at Al Haroneyah in the western part of the area, while it was during the previous Well inventory study which has been carried out from January until May 1984, by the WRAY-project ranged between 485 to 7100 µS/cm.

The field investigation indicated that the major part of the Wadi Surdud plain in quaternary aquifer system is fresh water excepting the western part, which outlined to the west of Al Munirah to Al Urj where the fresh water overlain by shallow brackish groundwater. Some kilometers to the west groundwater become saline groundwater especially in direction to As Salif Peninsula northwest direction where sabkha is predominantly.

Figure 9: Electrical Conductivity Distribution



- **Hydrogen - Ion Concentration (pH):**

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

If the pH value at 25C is 7, this means a natural water. An excess of hydrogen (H+) indicated an acid water with corresponding pH value lower than 7. Conversely, an excess of hydroxyl ion (OH-) indicates an alkaline water which has a pH value greater than 7.

The measured pH is an important parameter in the geochemical equilibrium. The degree of precision of pH measurements, however, requires attention to electrode maintenance, buffer solutions, and temperature corrections.

In Wadi Surdud pH varied between 6.4 and 8.8 with an average of 7.56

Figure 10 clearly illustrates the pH concentration in the area, which is normal in 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 0.6 mg/l in sample no. Su-060 (Al Haddadiyah) and 6.22 mg/l in sample no. Su- 082 (AL kashri) Figure 11.

Figure 10: pH values in Wadi Surdud Water Samples

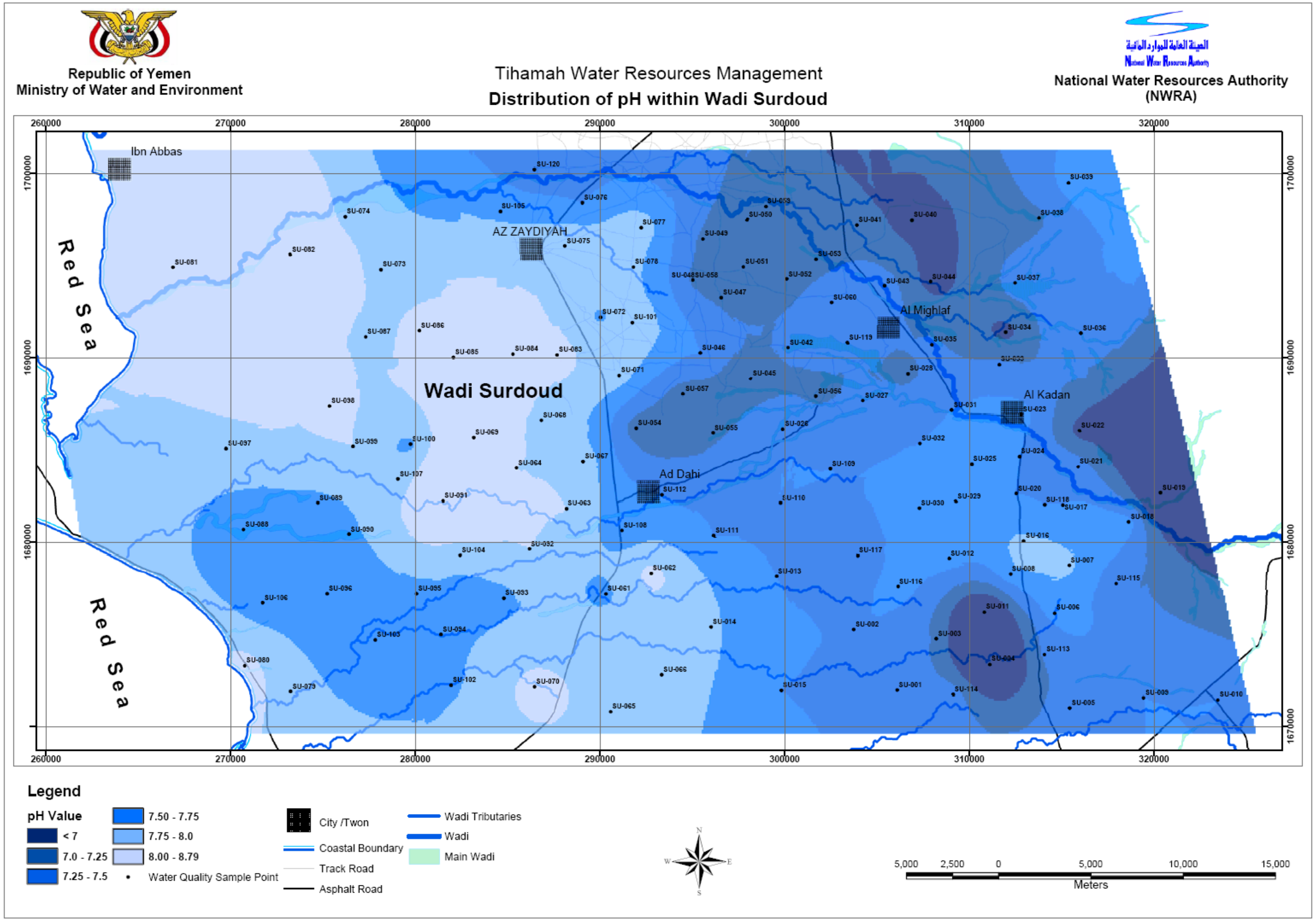
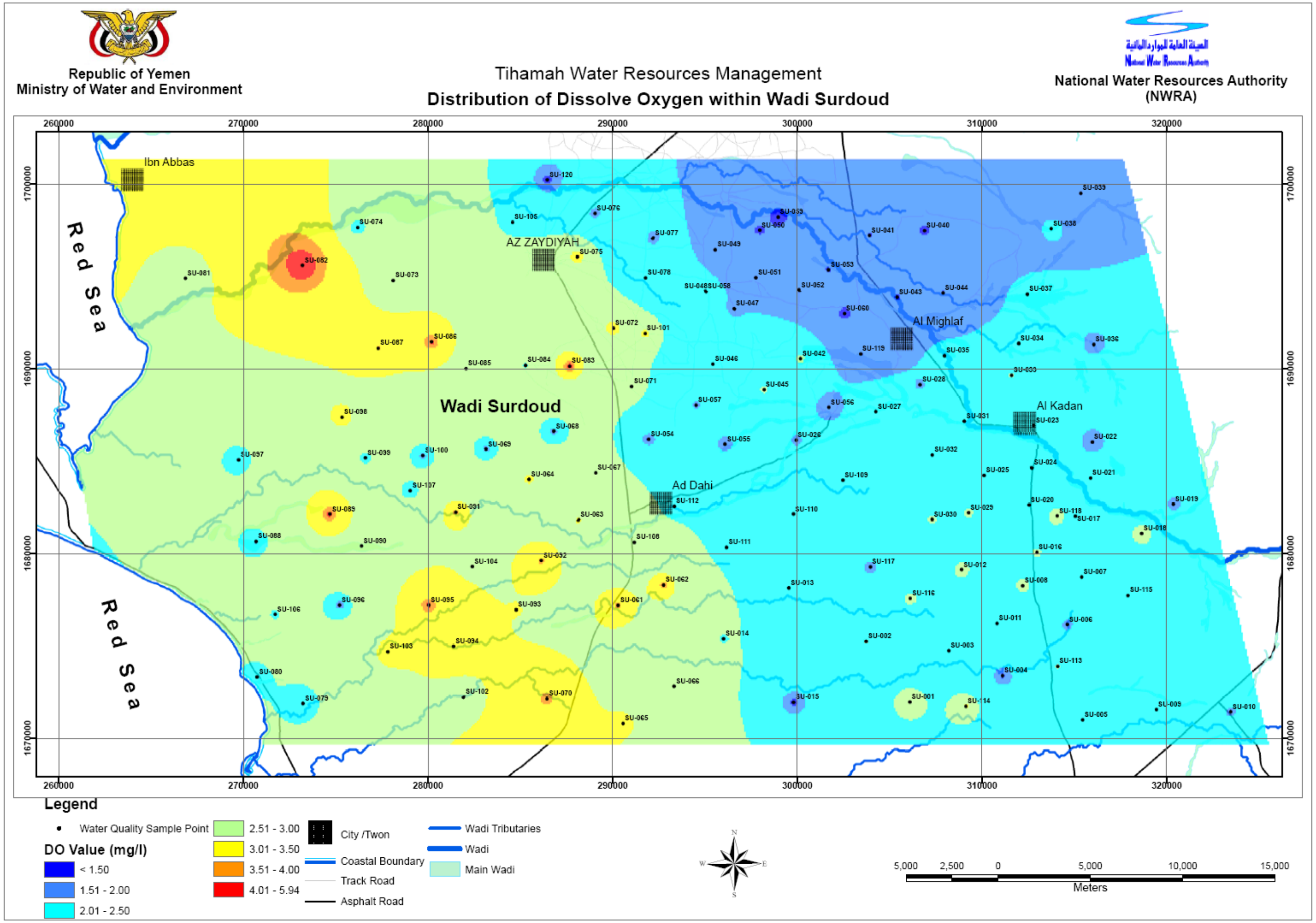


Figure 11: DO Distribution in Wadi Surdud Water Samples



- **Groundwater Temperature (oC):**

The temperature increases approximately 1C for each 30m of depth according to the geothermal gradient of the earth crust, so the groundwater temperature may refer to depth of water. Measurement of temperature is required for control of other measurements, as all other parameters are sensitive to temperature. For all water samples, temperature varied between 23.9 ^{o}C and 37.6 ^{o}C with average 27.65 ^{o}C in Wadi Surdud .

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
Florid	HACH Instrument
Iron	Atomic Adsorption

The results of analysis for Wadi Surdud is expressed in Annex III

2-3-3-2 Quality of the analyses

Quality of the analyses was checked by three methods:

Method 1- The ion balance, based on calculations of meq/L for cations and anions. The results are considered satisfactory if the calculated ionic balance error was less than 5%. 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% (Annex IV).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 Surdud 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.

3.3.4 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 Ca $(HCO_3)_2$, $CaCO_3$, and $CaSO_4$. Calcium are very important for water used in agricultural purposes, where it reduces the sodium absorption ratio of water and tries to diminish the effect of sodium through base cation exchange. In the study area, Calcium content ranges between 10 mg/l – 500 mg/l with average 77 mg/l. Figure 12 clearly illustrates the distribution the calcium concentration in the area, which is normal for all the area.

- **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 7.2 mg/l – 214 mg/l with average 44.2 mg/l. 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 around the Urj. There are no known cases of magnesium poisoning. High oral doses of magnesium may cause vomiting and diarrhoea.

- **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,

Figure 12 : Calcium Concentration in the study area

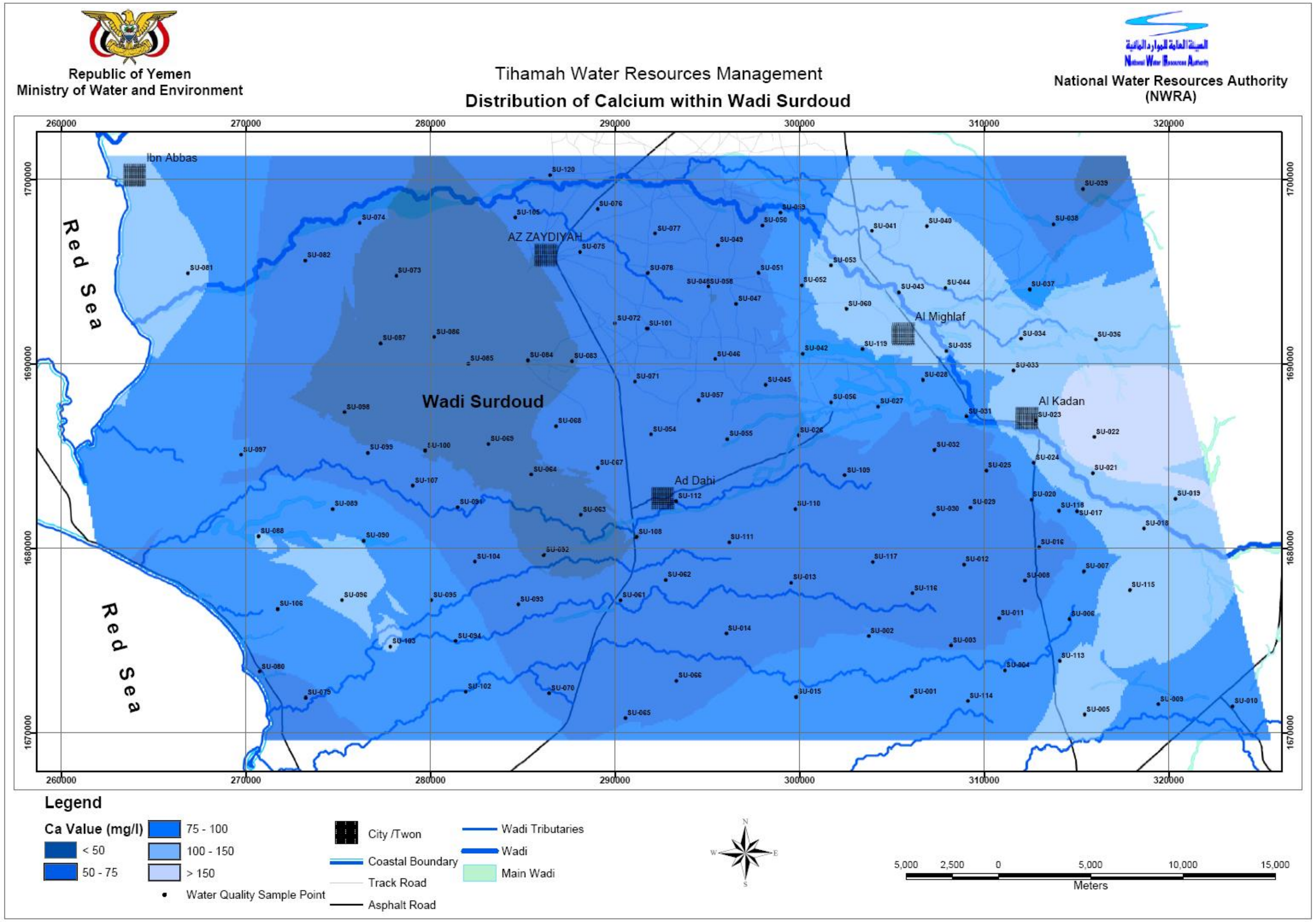
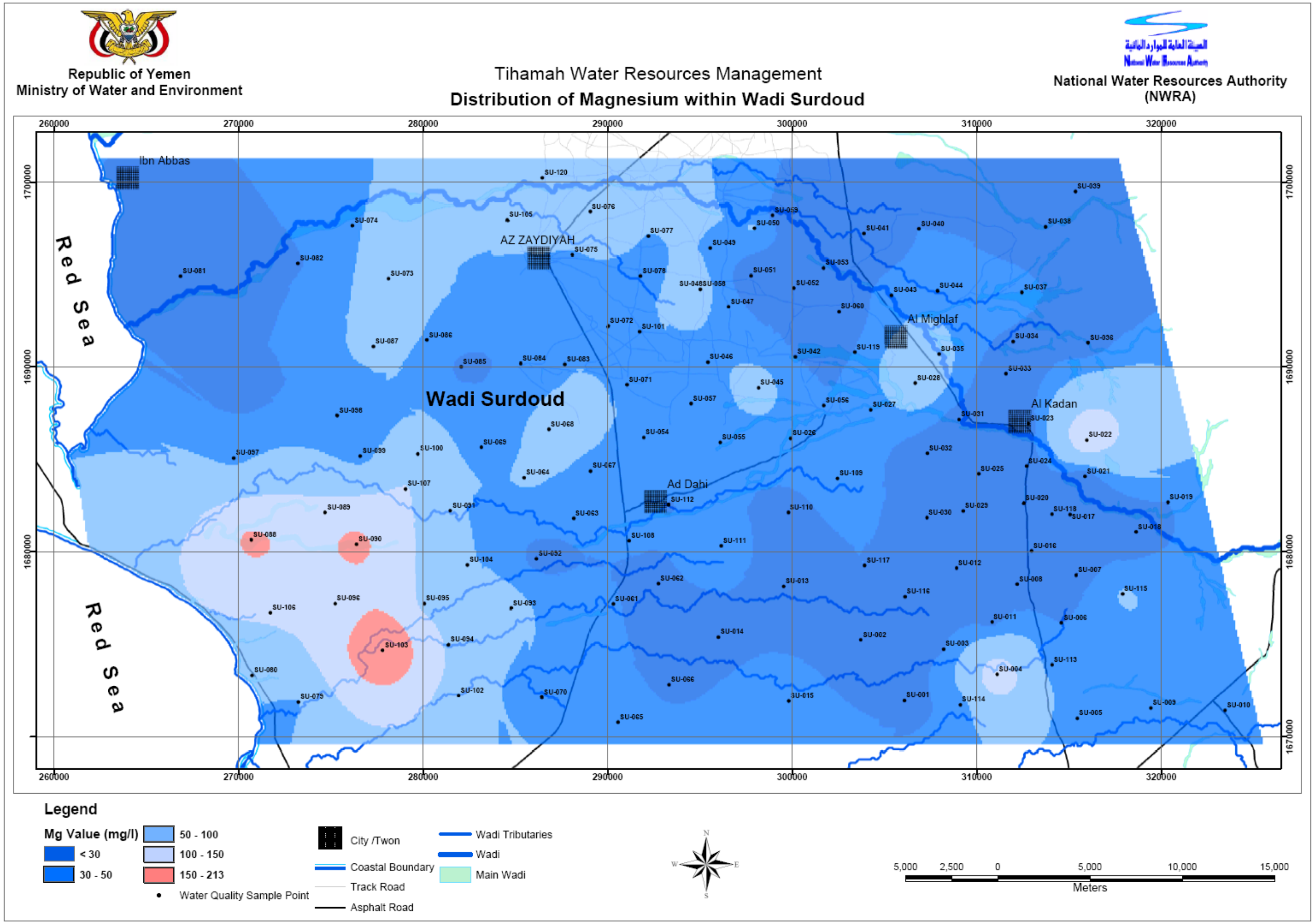


Figure 13: Magnesium Concentration in the study area



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 94 mg/l – 2185 mg/l with average 273 mg/l.

Figure 14 clearly illustrates increasing sodium element on the north- west of Wadi Surdud and extended on the coast line to south-west near Al Urj village .

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 sedimentary rock. The main source of potassium in groundwater is potassium feldspars and feldspathoid in igneous rocks, clay minerals in sedimentary rocks and in evaporate rocks. Potassium salts in water are KCl and in evaporate rocks. Potassium salts in water are KCl and K_2SO_4. In the study area, potassium content ranges between 0.6 mg/l – 9.8 mg/l with average 3.3 mg/l.

Figure 15 clearly illustrates the distribution the potassium concentration in the area, which is normal for all area.

2- Major anions

- **<u>Carbonate ($CO_3^{=}$) and Bicarbonate (HCO_3^-)</u>**

The main sources of carbonate and bicarbonate is carbon- dioxide (CO2) from the atmosphere. Carbon dioxide released within the soil by organic decay and from plant respiration. In Wadi Surdud carbonate was found in 3 samples and ranged between 15 – 30 mg/l with an average 22.5 mg/l.

The concentration of bicarbonate in Wadi Surdud ranges between 230 mg/l – 1647 mg/l with average458 mg/l. Figure 16 shows the distribution of the bicarbonate concentration in the study area, Many areas contain a high concentration of bicarbonate, but most of the areas with Bicarbonate concentration are in the north west of Wadi Surdud near Ibn Abbas village.

Figure 14: Sodium Concentration in the study area

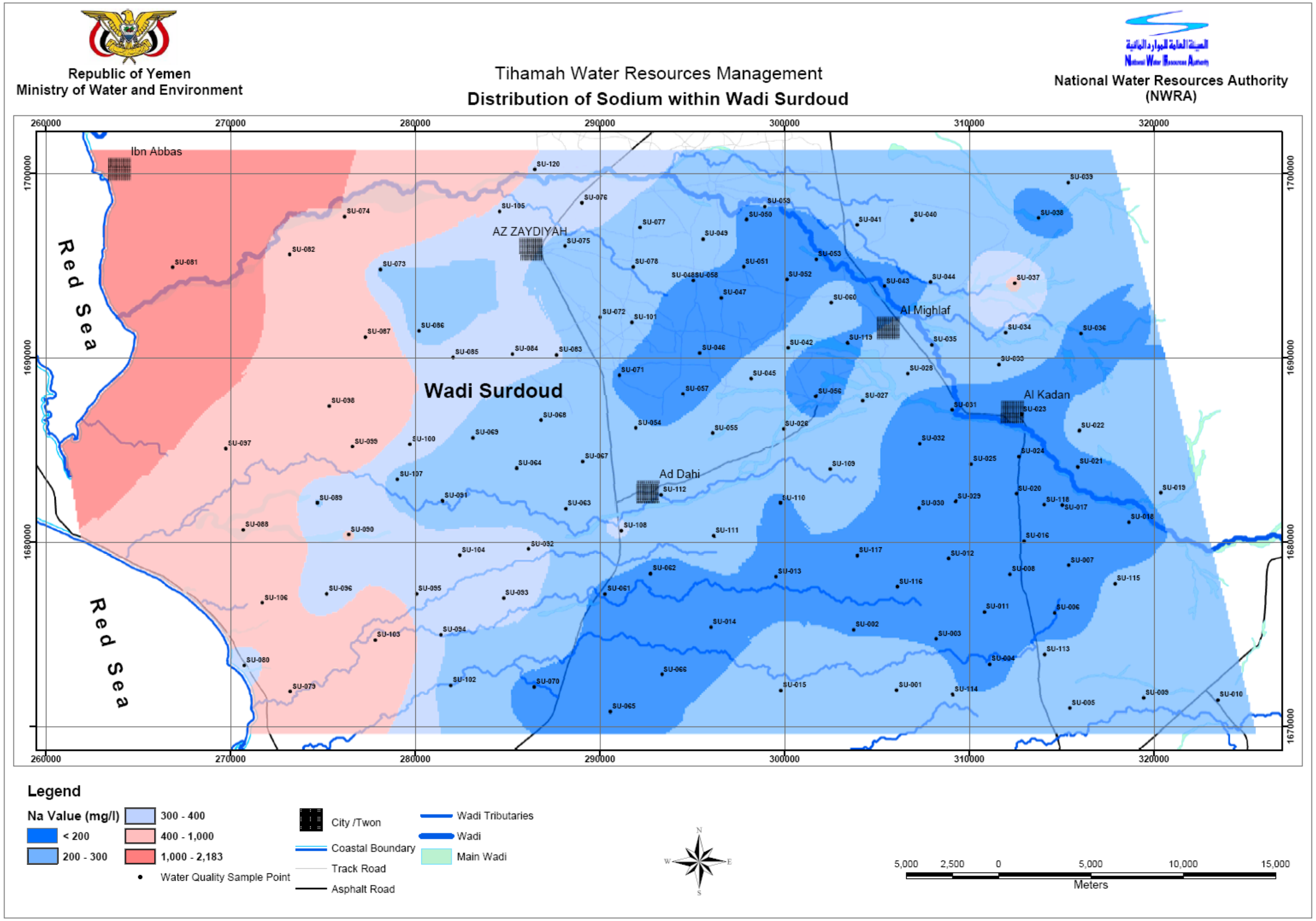


Figure 15: Potassium Concentration in the study area

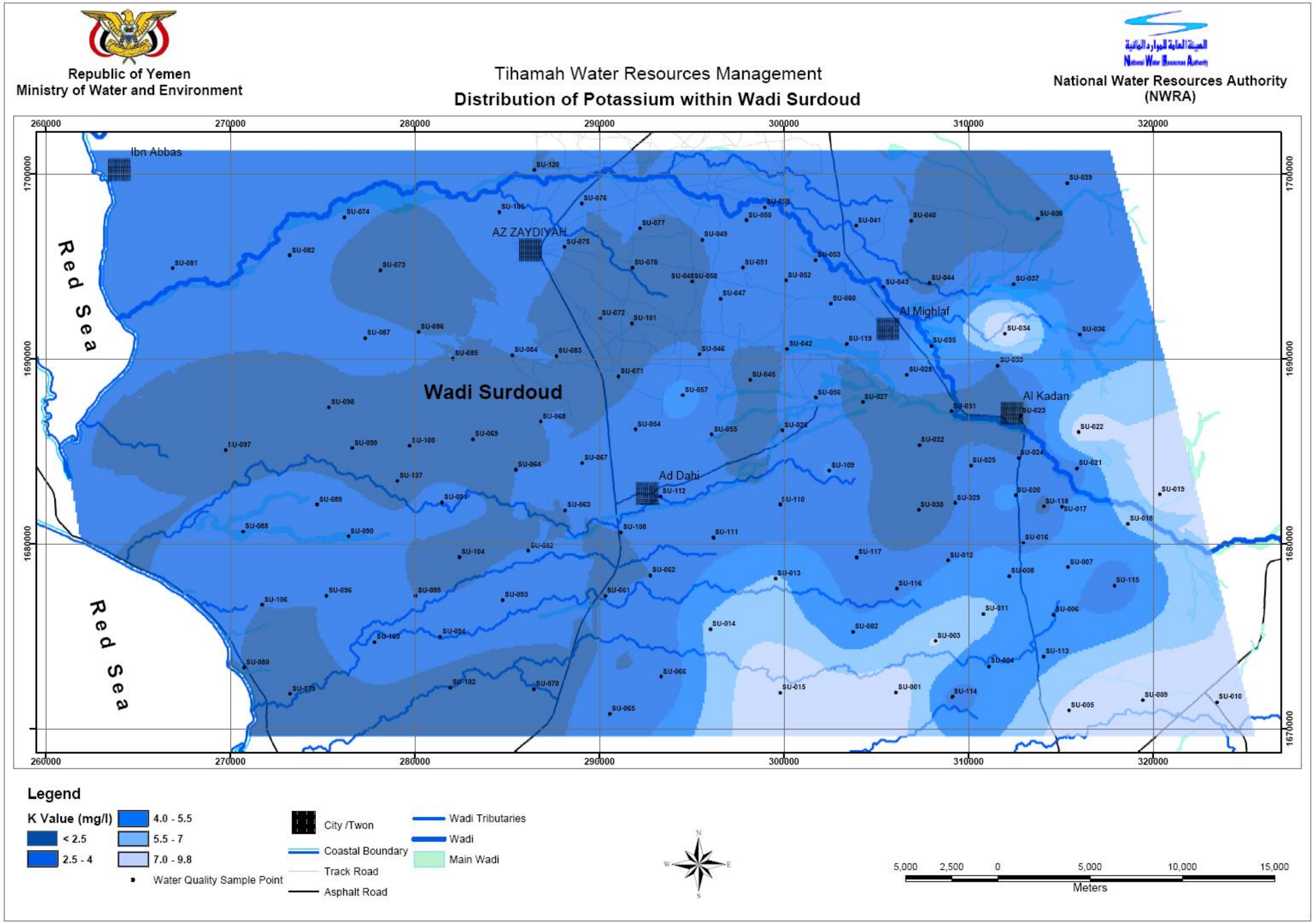
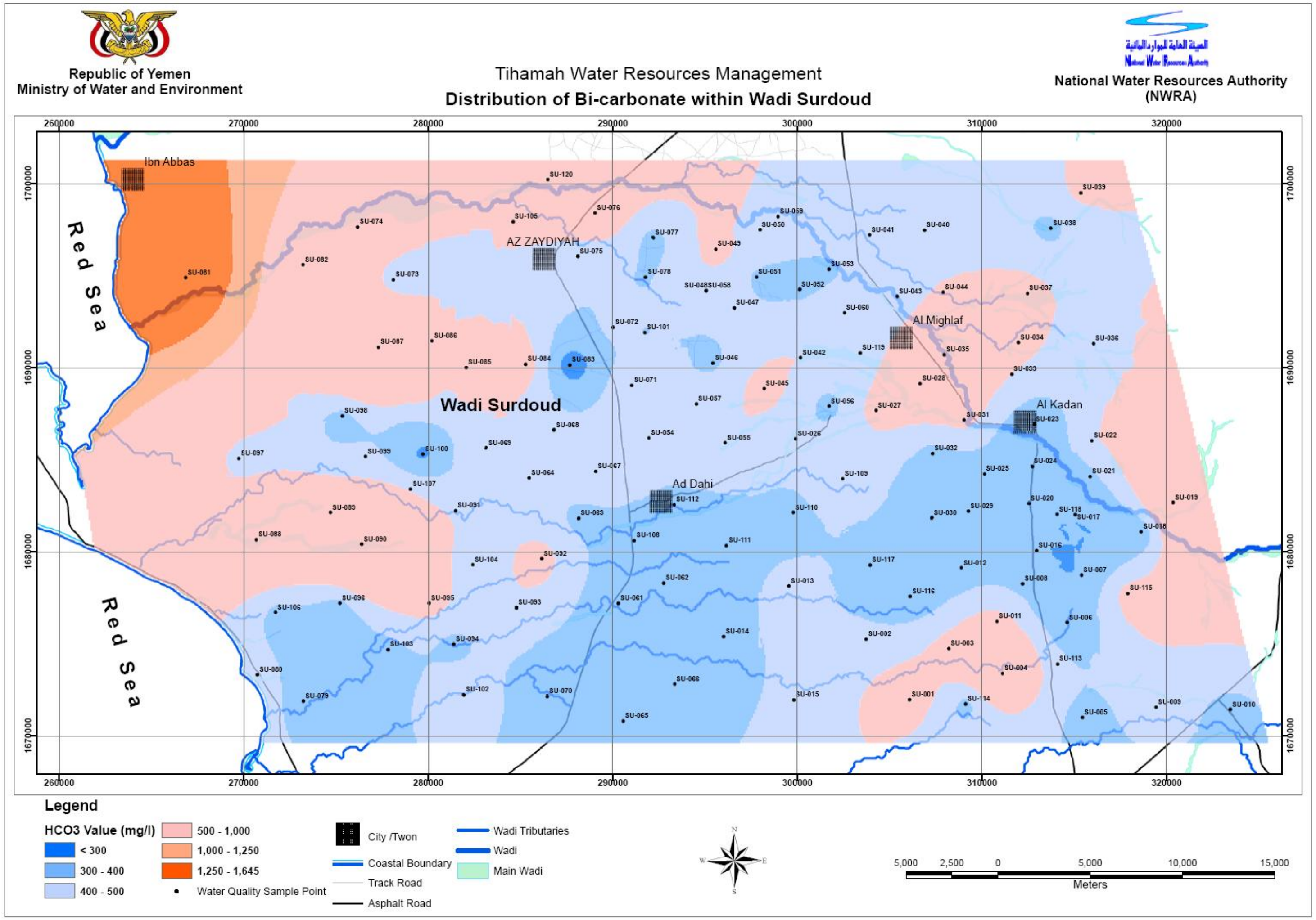


Figure 16: Bicarbonate concentration in Wadi Surdud Water Samples



- **Sulphate (SO_4)**

Sulphate is not a major constituent of the earths outer crust, but is widely distributed in reduced form both in igneous and sedimentary rocks of metallic sulfides. These sulfides (such as pyrite) are oxidized to yield Sulphate ions which are carried off in the water (Hem 1970). In the study area, Sulphate content ranges between 48 mg/l – 336 mg/l with Average 107 mg/l.

Fig. 17 gives Sulphate concentration and the area could be categorized as normal as for Sulphate is concerned.

- **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, Chloride concentration map (Figure 18) shows an increase in chloride contamination in the coastal area with the same increasing in sodium element, So, this figure implies that the increase in concentration of the chloride may be the result of salt water intrusion into fresh water (chloride is the main anion in the sea water).

Chloride content in Wadi Surdud ranges between 53 mg/l – 2226 mg/l with average 315 mg/l.

The chloride contamination increases closer to the coast especially in the down stream (figure 19) of the wadi.

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

The figure clearly illustrates the general trend of chloride in the study area, rising steadily towards the downstream. This trend extends along the entire Wadi from the east to the west.

Figure 17: Sulfate Concentration in the study area

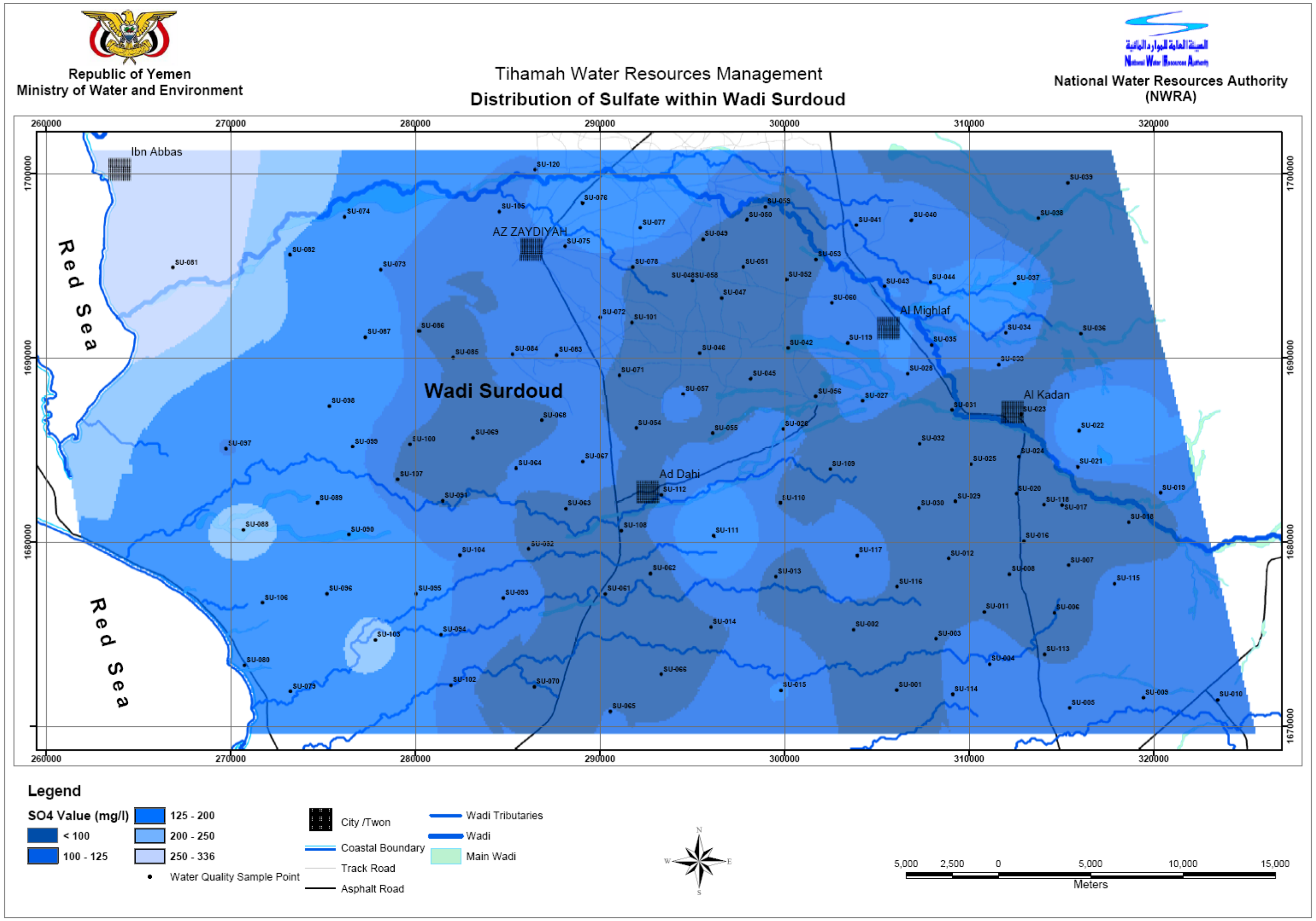


Figure 18: Chloride Concentration in the study area

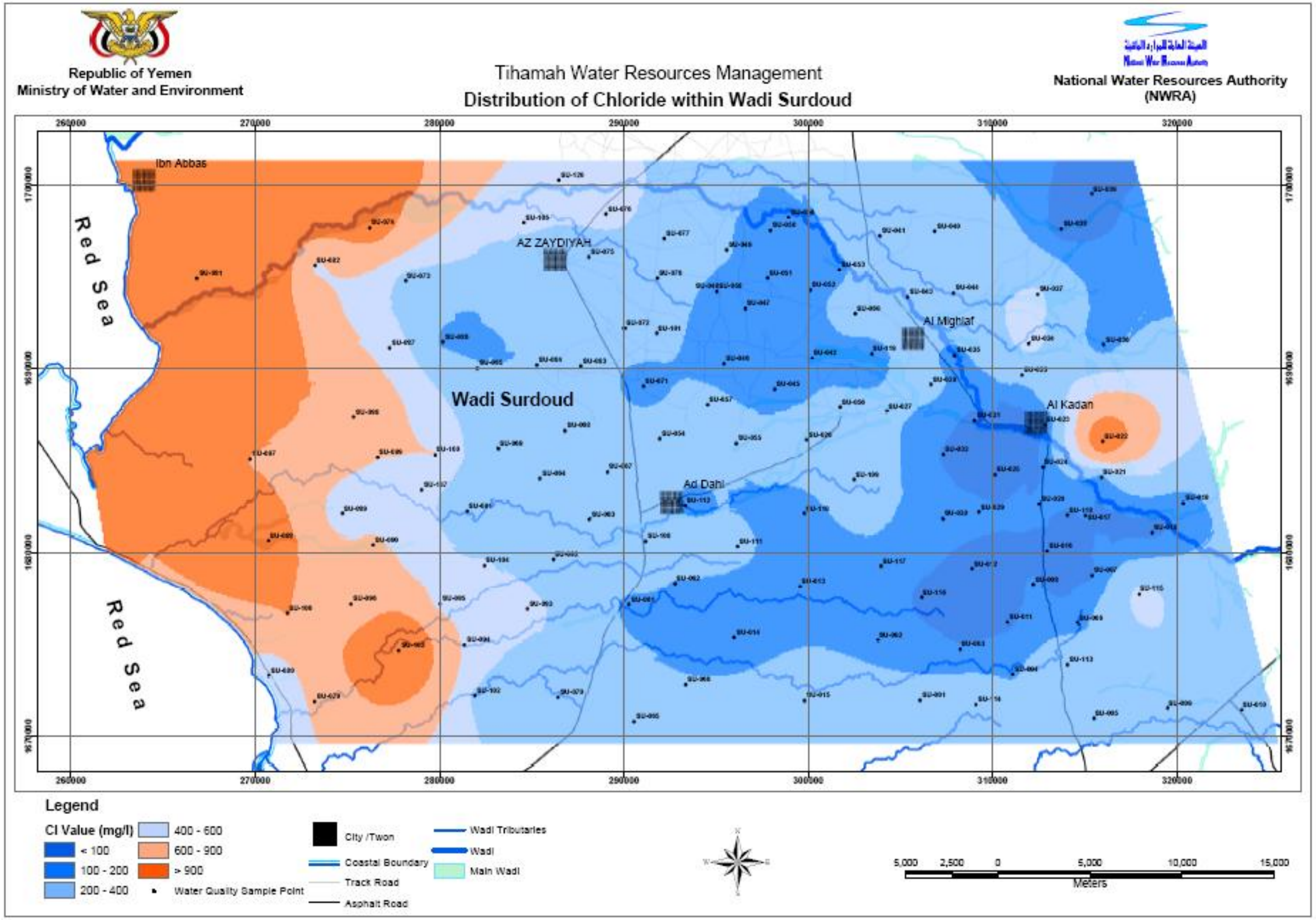
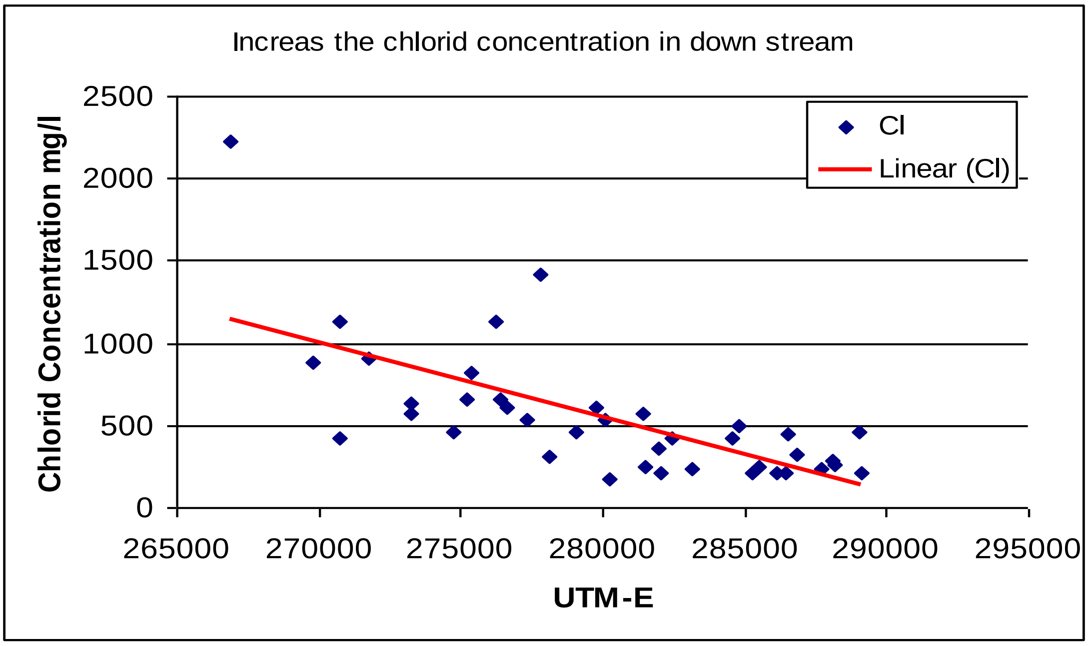


Figure 19: Increas the chlorid concentration in down stream



- **Nitrate NO_3**

In the 121 analyzed samples from Wadi Surdud, nitrate ranges from 6.5 mg/l - 97 mg/l with an average of 40 mg/l. Twenty three samples have shown values higher than 50 mg/l (Yemen and WHO Guideline Value) and fifty eight 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 58 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 the groundwater in the form of ammonium that oxidizes fast into nitrite and finally into nitrate (stable form in the presence of oxygen). This remarkable spreading of nitrates in the groundwater of this area represents a major problem for drinking water supply. It brings about methemoglobinemia in babies. Moreover, when compounded with some food preservatives it is suspected to unleash carcinogenic activity. Figure 20 shows nitrate distribution in the study area .

- **Fluoride (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 0.065 - 2.38 mg/l in Wadi Surdud .

There are 30 samples exceed the Yemeni standard for drinking water (Yemen standard ranges between 0.5-1.5 mg/l) 10 of these wells use for supply. The areas which suffer from this phenomena are Al Kadaf, Al Mashaf, Al Gadidah, A'azan, Kadaf and Al Maarofiah villages.

Figure 21 clearly illustrates the distribution the floride concentration in the area.

- **Total Hardness**

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

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

In the study area, values range from 75 - 1880 mg/l with average 382 mg/l. There are 20 samples exceed the Yemeni standard for drinking water (Yemen standard ranges between 100-500 mg/l) 3 of these wells use for supply. The areas which suffer from this phenomena are Mahal Al Koa, Dir Al Kaderi and Al Herthah villages.

Figure 22 clearly illustrates the distribution of the total hardness concentration in the area.

Figure 20: Nitrate Concentration in the study area

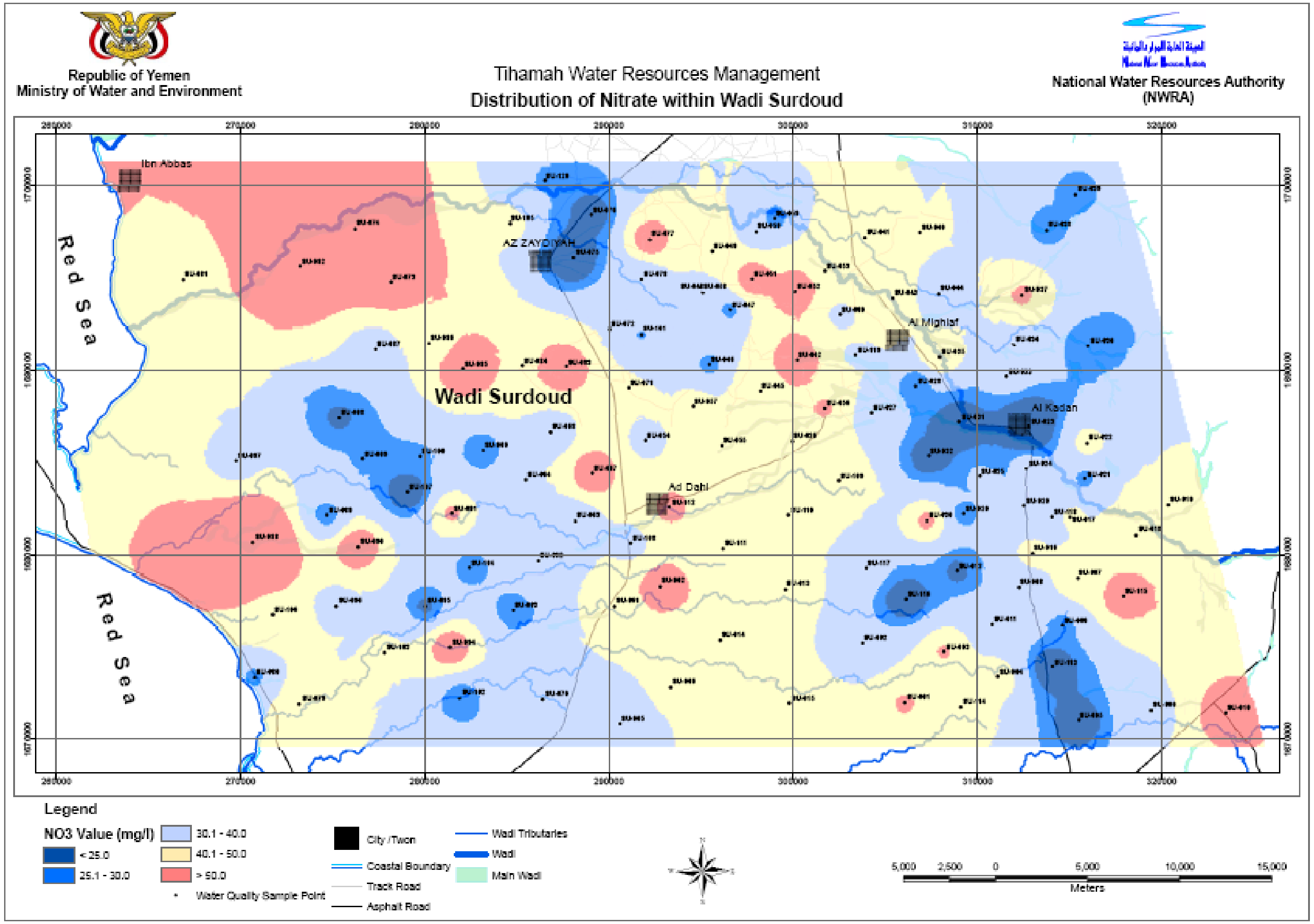


Figure 21: Fluoride Concentration for Wadi Surdud water samples

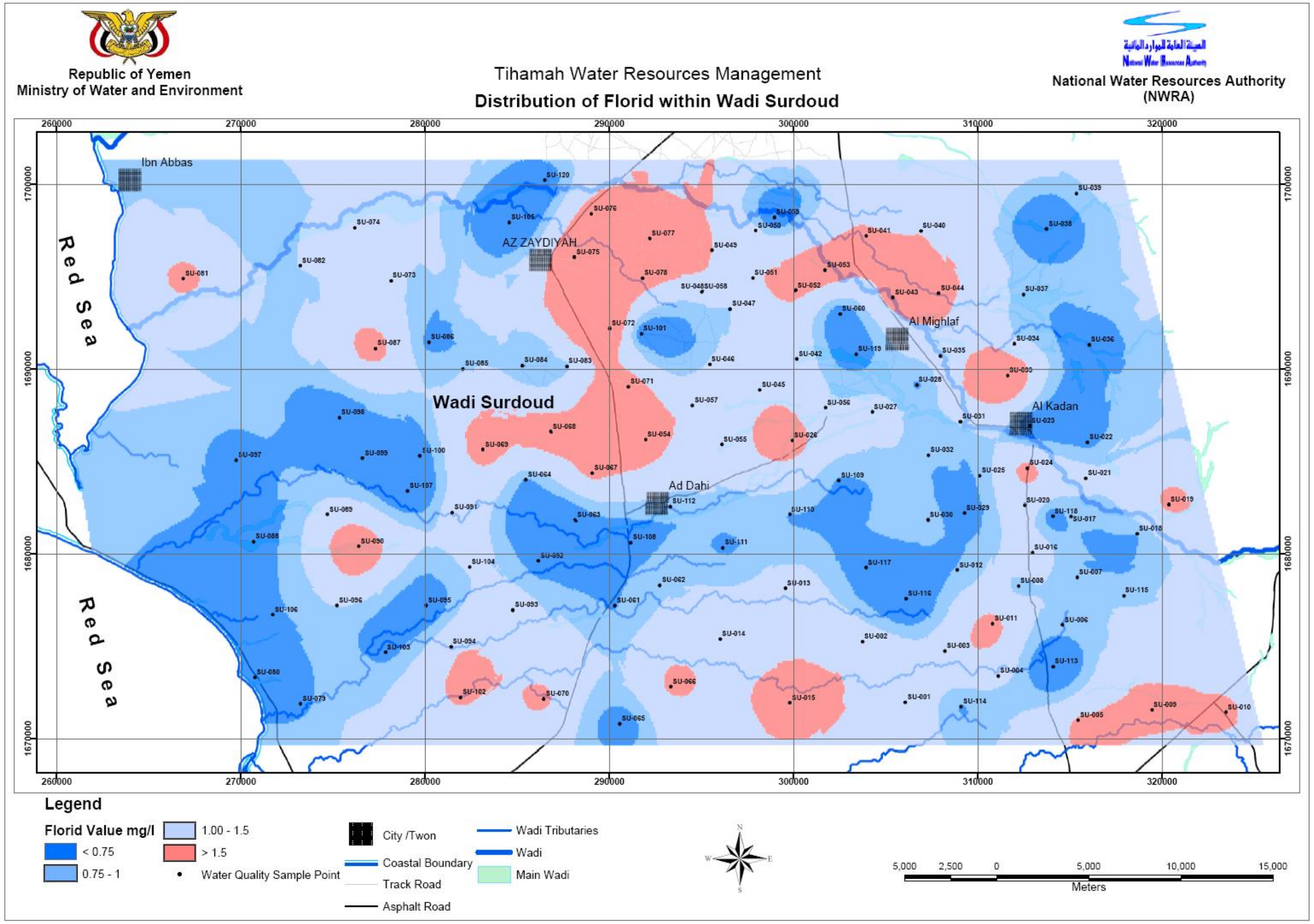
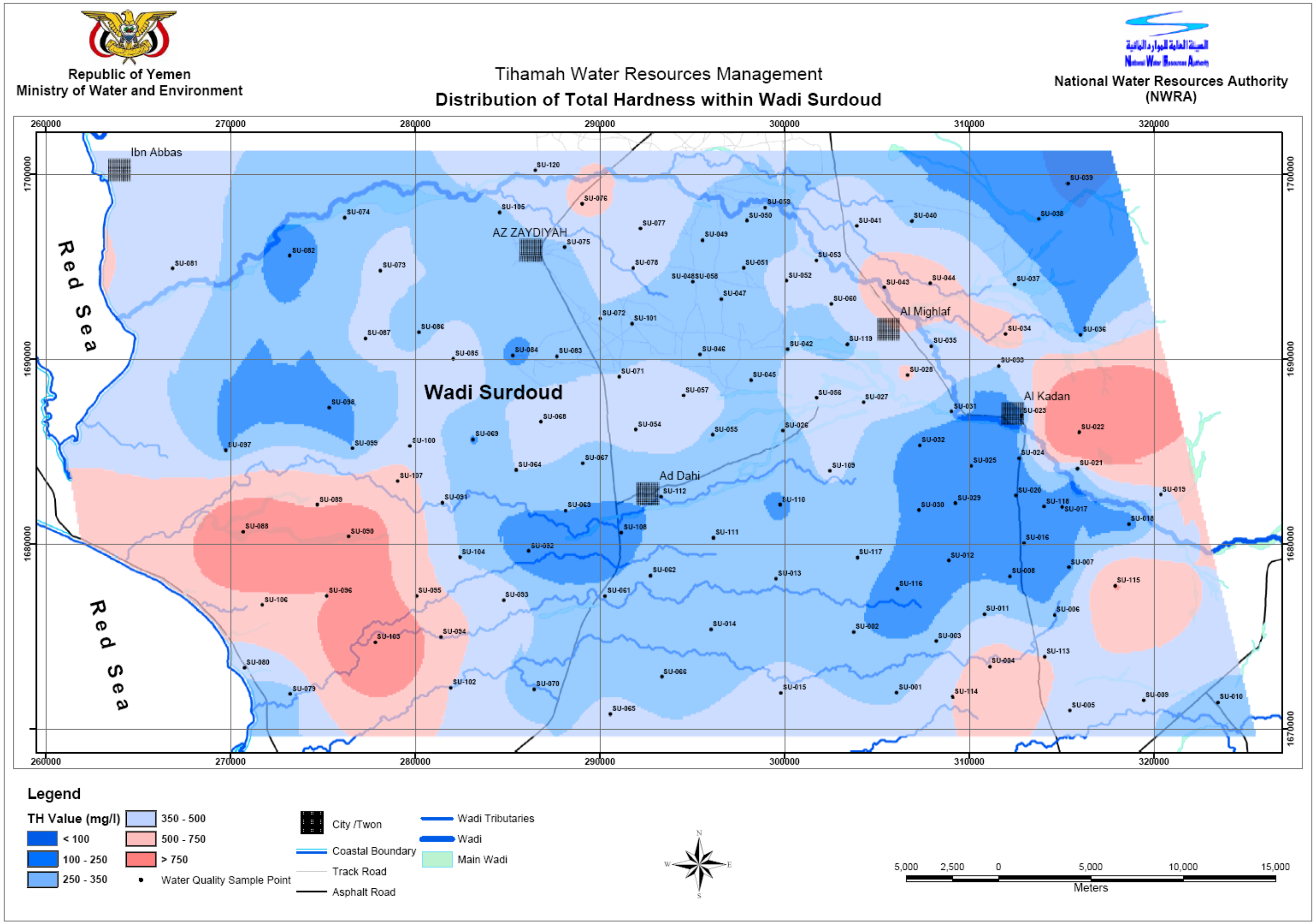


Figure 22: Total Hardness values for Wadi Surdud water samples



3 Chemical water type in Wadi Surdud

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

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

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

According to The Piper diagram that was used to identify groundwater chemical water types for 121 samples collected from Wadi Surdud, the analysis of the main ion chemistry and by using conversion constants to transform anion and cation values - expressed in mg/l - into meq/l, it is possible to interpret the chemical water type of a given sample of water.

To explain the chemical water types for all area , the Wadi was divided into two parts; upstream including the area more than UTM – E 290000m; down stream less than 290,000m.The Piper diagram has allowed for the identification of two chemical water type, which relate directly to the history and development of the groundwater. Also, the chemical types for the two parts of the wadi are presented in the figures (23 A, B) and discussed below.

3-1 Types of the chemical water

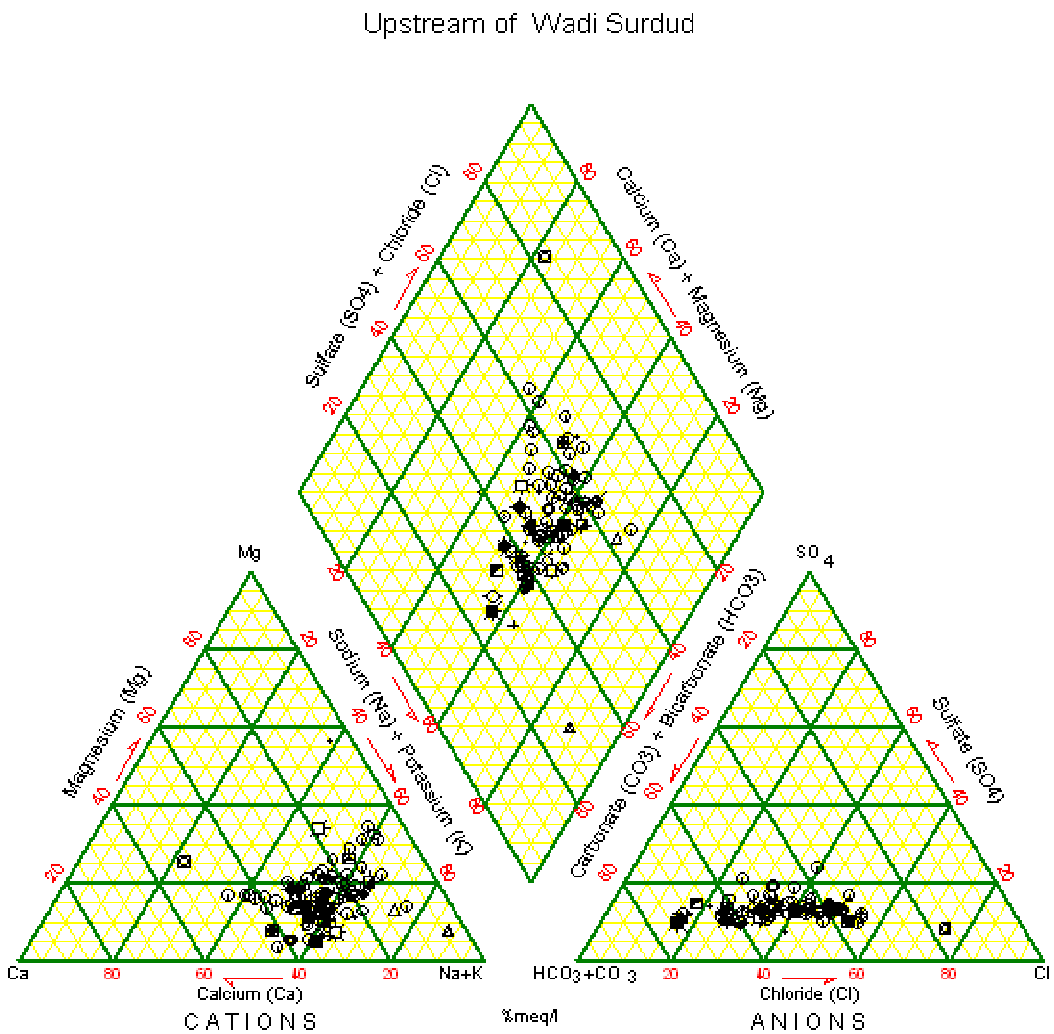
3-1-1 Type1: Indiscriminate Ions (Mixed) Waters

This groundwater type appears to represent a hydrochemical evolution of Bicarbonate water (recharged type) which not appear in Wadi Surdud, this mean that no there any recharge in the area, at least during the last few years.

This water type is found in about 78 sample collected from Up stream (95%) of all samples which were collected from this part, while 5% are (Na+K)(SO_4+Cl), Ca SO4, and Na HCO3 waters.

This water type appears to evolve due to enrichment of other anions such as SO_4 or Cl, as it passes through source(s) of these ions. As the water type evolves, this type may be evolution to type 2 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, this happens due to high pumping in the Wadi and low rainfall and low recharge on the upper catchment's area (Figure 23).

Figure 23: The Piper Digram of Upstreem



3-1-2 TYPE 2: (Na+K)(SO_4+Cl)

This type is rich in Na cations and Cl anions, and is mainly present in the down stream of the Wadi. This water type represents a hydrochemical evolution of Type 1. figure 24 shows the distribution of the samples in downstream and figure (25) shows the increase in average of Na & Cl in the downstream side.

All Samples which are collected from down stream are from this type, which indicates that this area is effected by the salt water intrusion to the groundwater. It occurs 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.

Figure 24: The Piper Diagram of Down Stream

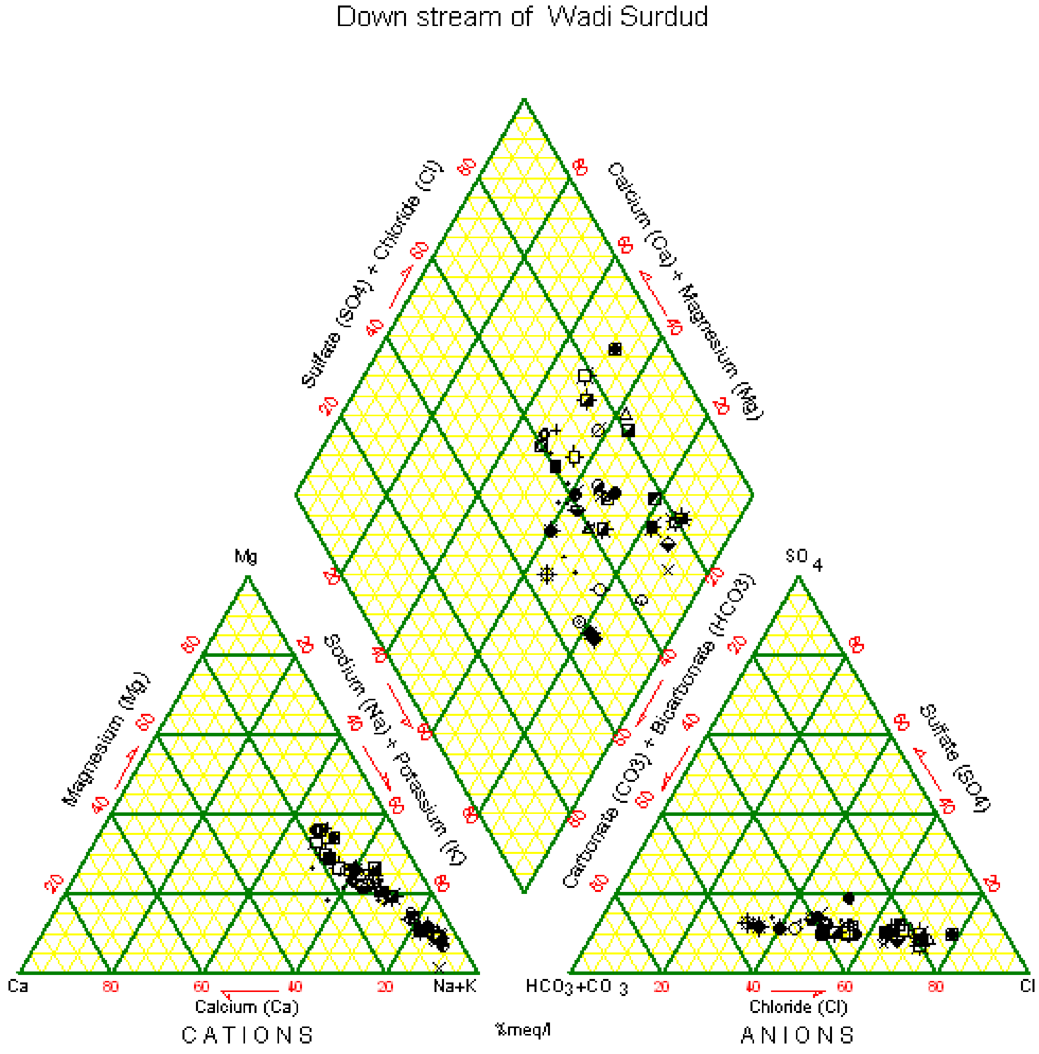
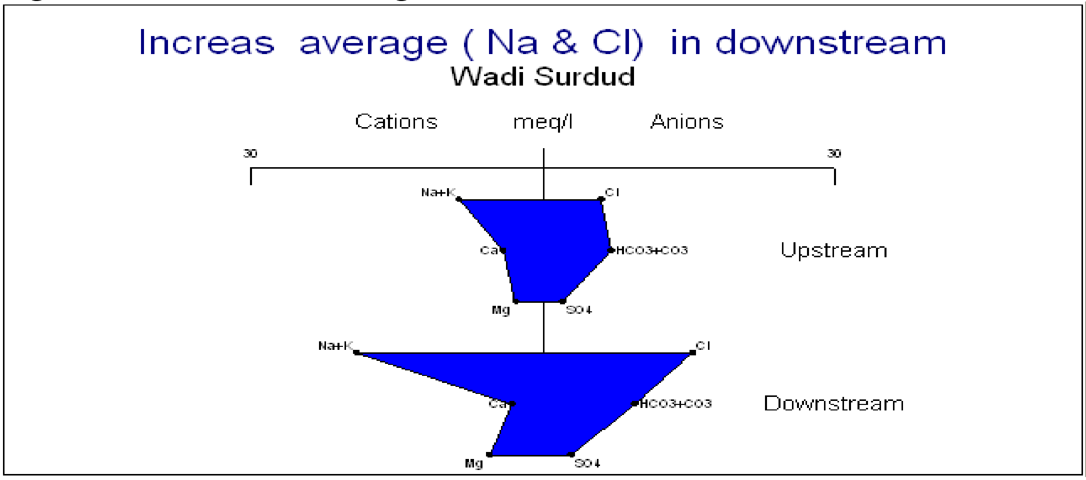


Figure 25:Increase the average of Na & Cl in the downstream



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 26.

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

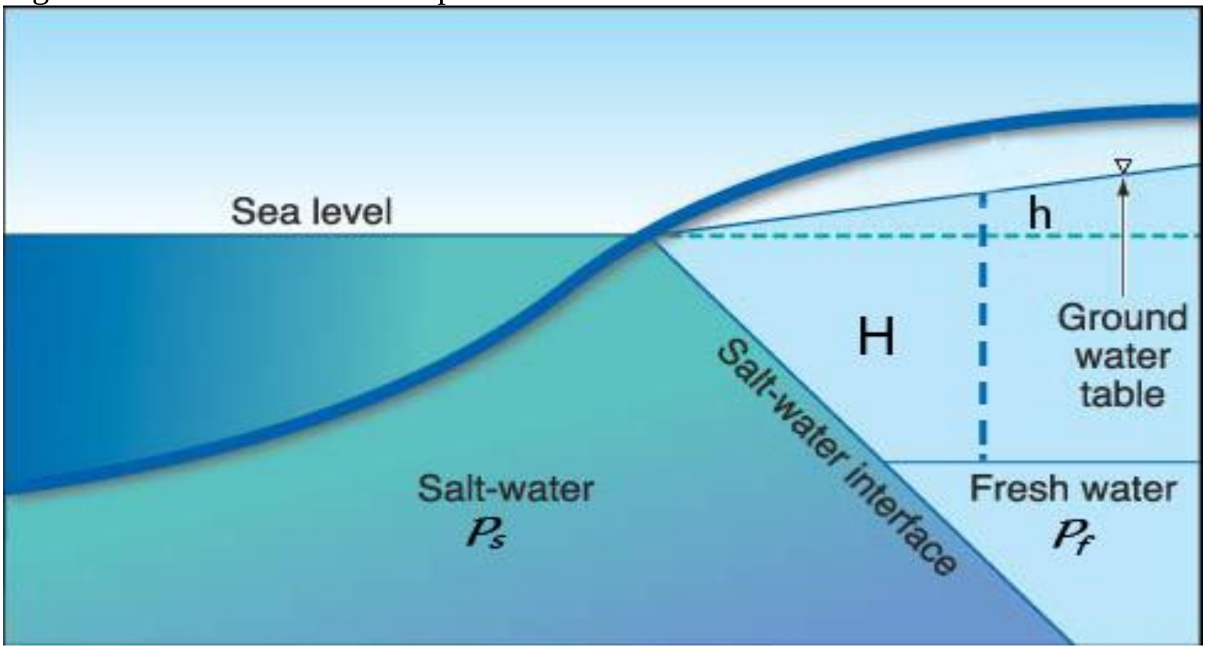
H is the depth of fresh water below sea level

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 26: Salt water Intrusion phenomena



According to this relation, if the water table in an unconfined coastal aquifer is lowered by 1 m, the salt-water interface will rise 40 m.

In Wadi Surdud , especially in Al Urj , Al Jarb ,Ras Isa and Al Haroniah 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- Groundwater Use

4-1 Introduction

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

In total, 121 water samples were analyzed throughout Wadi Surdud 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.

4-2 Drinking (Domestic) Water

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 35 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 are given in Table (5).

It should noted that very few samples were found to be over the Maximum Permissible Limit (MPL), and more than 85% of the samples had levels between Optimal Limits and Maximum Permissible Limit.

With respect to Nitrate element, only 19 % of samples (23 sample) were found over Maximum Permissible Limit (MPL). These samples were concentrated in the west / north of the study area, and for Chloride, about 11% of samples (13 samples) were found over Maximum Permissible Limit (MPL).

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

Also for fluoride, about 25 % (30 sample) were found over Maximum Permissible Limit (MPL).

Table 5: Suitability of water samples for drinking water in Wadi Surdud

Element	Optimal Limits (mg/l)	Samples within (OL)	Maximum Permissible Limit(mg/l)	Samples within (MPL)	Samples over the (MPL)
TDS	650	15	1500	81	25
Calcium	75	78	200	40	3
Magnesium	30	49	150	69	3
Sodium	200	48	400	60	13
Potassium	8	117	12	4	
Bicarbonate	150		500	90	31
Chloride	200	47	600	61	13
Sulfate	200	118	400	3	
Nitrate	10	1	50	97	23
Iron	0.3	2	1	119	
Flouride	0.5	21	1.5	70	30
Total Hardness	100	1	500	100	20

According to the field information of sampled wells, only 29 wells are in use for drinking water and 6 wells are in use for domestic .

Only 15 well are borehole well, 8 wells are dug and 12 wells are dug/bore. Results of drinking water quality classifications for samples collected from these wells are given in table 6.

It should noted that 74% of the supply and domestic wells (28 wells) are classified as unsuitable for drinking water on account of one element or more

exceeded the Yemeni standard. More than 28 % (10 samples) of samples were had levels higher than the MPL with respect to Nitrate and more than 34% of samples (12 sample) had levels higher than the MPL with respect to fluoride.
Only one sample (SU-081) which situated in Al Haroniah village had 5 elements exceed the Yemeni standard while there are 2 samples exceed the Yemeni standard in 4 elements, table 7 shows these samples and their location.

Table 6:Water suitability for samples collected from water supply projects

Element	Optimal Limits (mg/l)	Samples within (OL)	Maximum Permissible Limit (mg/l)	Samples within (MPL)	Samples over the (MPL)
TDS	650	3	1500	26	6
Calcium	75	26	200	9	
Magnesium	30	13	150	22	
Sodium	200	11	400	21	3
Potassium	8	33	12	2	
Bicarbonate	150		500	24	11
Chloride	200	10	600	24	1
Sulfate	200	34	400	1	
Nitrate	10	1	50	24	10
Iron	0.3	1	1	34	
Flouride	0.5	7	1.5	16	12
Total Hardness	100		500	32	3

Table 7: The water samples exceed the Yemeni standard of Drinking Water

Well No	Site	well type	Location		N0. of exceed elements	Exceed Element Type
			UTM East	UTM North		
SU-001	Al Marba'	Dug	306091	1671964	2	HCO3, NO3
SU-010	A'azan	Dug/Bor	323470	1671427	2	NO3,F
SU-015	Al gadida	Dug/Bor	299818	1671940	1	F
SU-019	Thowb Bani mahal	Dug	320364	1682667	2	HCO3,TDS
SU-024	Al Nassery	Dug/Bor	312709	1684629	1	F
SU-028	Al Herthah	Bore	306677	1689130	2	HCO3, TH
SU-030	Al Saied Mohammed	Dug	307296	1681833	1	NO_3
SU-037	Al Maqana'a	Dug	312466	1694029	4	Na,TDS, HCO3, NO3
SU-051	Dar Da'aam	Dug/Bor	297784	1694928	1	NO_3
SU-056	Al Mwahebah	Bore	301723	1687903	1	NO_3
SU-066	salimia	Dug/Bor	293348	1672812	1	F
SU-067	Kadaf	Dug/Bor	289091	1684364	2	NO3,F
SU-069	Deer Al bahri	Bore	283163	1685644	1	F
SU-071	Al Marofia	Bore	291057	1689036	1	F
SU-072	Al Mashaf	Bore	290032	1692194	1	F
SU-073	moniera	Bore	278139	1694773	1	NO_3
SU-078	Rbat	Bore	291802	1694917	1	F
SU-081	Al haronia	Dug	266879	1694901	5	Na,Cl,TDS,NO3,F
SU-083	Dir Aomer	Bore	287686	1690136	1	NO_3
SU-084	hashabra	Dug/Bor	285294	1690184	1	HCO_3
SU-085	Kadri	Dug	282071	1690006	3	HCO_3,NO_3, TH
SU-086	Hard	Bore	280222	1691446	1	HCO_3
SU-087	Arid	Dug/Bor	277316	1691110	4	HCO_3,F,Na,TDS
SU-089	Mahel AL koa	Bore	274713	1682124	3	HCO_3,TDS, TH
SU-093	Al dbarsh	Bore	284780	1676947	1	TDS
SU-120	Deer Al Zueh	Bore	286483	1700223	2	TDS, HCO3

4-3 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.

4-3-1 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	94	Salinity will adversely affect most plants; requires selection of salt-tolerant plants, careful irrigation, good drainage, and leaching.
C4	> 2250	27	Generally unacceptable for irrigation, except for very salt tolerant plants, excellent drainage, frequent leaching, and intensive management.

Based on this classification, the most of samples were C3 water type (94 sample) with EC values between 750- 2250 (µS/cm), while 27 samples were C4 with EC > 2250 µS/cm). These samples generally refer to unacceptable for irrigation, except on very salt tolerant plants with field conditions including, excellent drainage, frequent leaching, and intensive management.

4-3-2 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 adsorbed 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.

Most the samples collected during this study (108 sample) belong to the S1 group with SAR values of < 10, except 8 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.

The quality classification of irrigation water, based on conflation the salinity (EC) values and SAR value is given in Table 10.

Table 9: Classification of irrigation water based on SAR values

Level	SAR	No of samples	Hazard
S1	<10	108	No harmful effects from sodium
S2	10-18	8	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

Table 10:Classification of irrigation water based on SAR value

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**	4	4	None	None
Low	**<10**	18	90	None	None
Total		27	94	None	None

Bases on the above table, 5 sample had very high salinity and very high and high sodium hazard, the quality of thes water is very poor and not suitable for irrigation (Su- 83,74,82,97 and 98).

22 samples had very high salinity and medium and low in sodium hazard, meaning the water is poor for irrigation.

4 samples had high salinity and medium sodium hazard, indicating marginal water quality. 90 samples were admissible for irrigation.

4-3-3 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

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

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 4 samples had SSP values between 20 and 40 indicating good water classification.

66 sample had SSP 40- 60 indicating permissible water classification, 42 sample had SSP values between 60 and 80 indicating doubtful water classification, while 9 sample had SSP > 80 indicating the water unsuitable for irrigation. These wells are: (well no. Su- 39,74,81,82,85,92,97,98,99).

Table 11:Classification of irrigation water based on SSP (Todd 1980).

Water Class	SSP	EC µs/cm	No of Samples
Excellent	< 20	> 250	None
Good	20-40	250-750	*4
Permissible	40-60	750-2000	66
Doubtful	60-80	2000-3000	42
Unsuitable	> 80	> 3000	9

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

4-4 Hydrochemical Criteria for Industrial uses

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 Surdud there are many small factories about 18 wells.

Some of the factories such as tanneries and block factories do not need high quality water, while others like water purification Plant (Assafi Water), and Ice plant, need high 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 Surdud (alluvium Basin)

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 Surdud and the larger tributaries, an area of approximately 2520 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 (Tihamah Authority) 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 cesspits. 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 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, 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 Surdud is composed mainly of unconsolidated alluvium consists of clay, sand and gravel.

The depth to water level in the area 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 on the coast and in east area near the upper catchment with average depth to water 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 20 - 50 m

This type is concentrated in the mid and down stream with average depth to water are 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 deeper water level >50 m

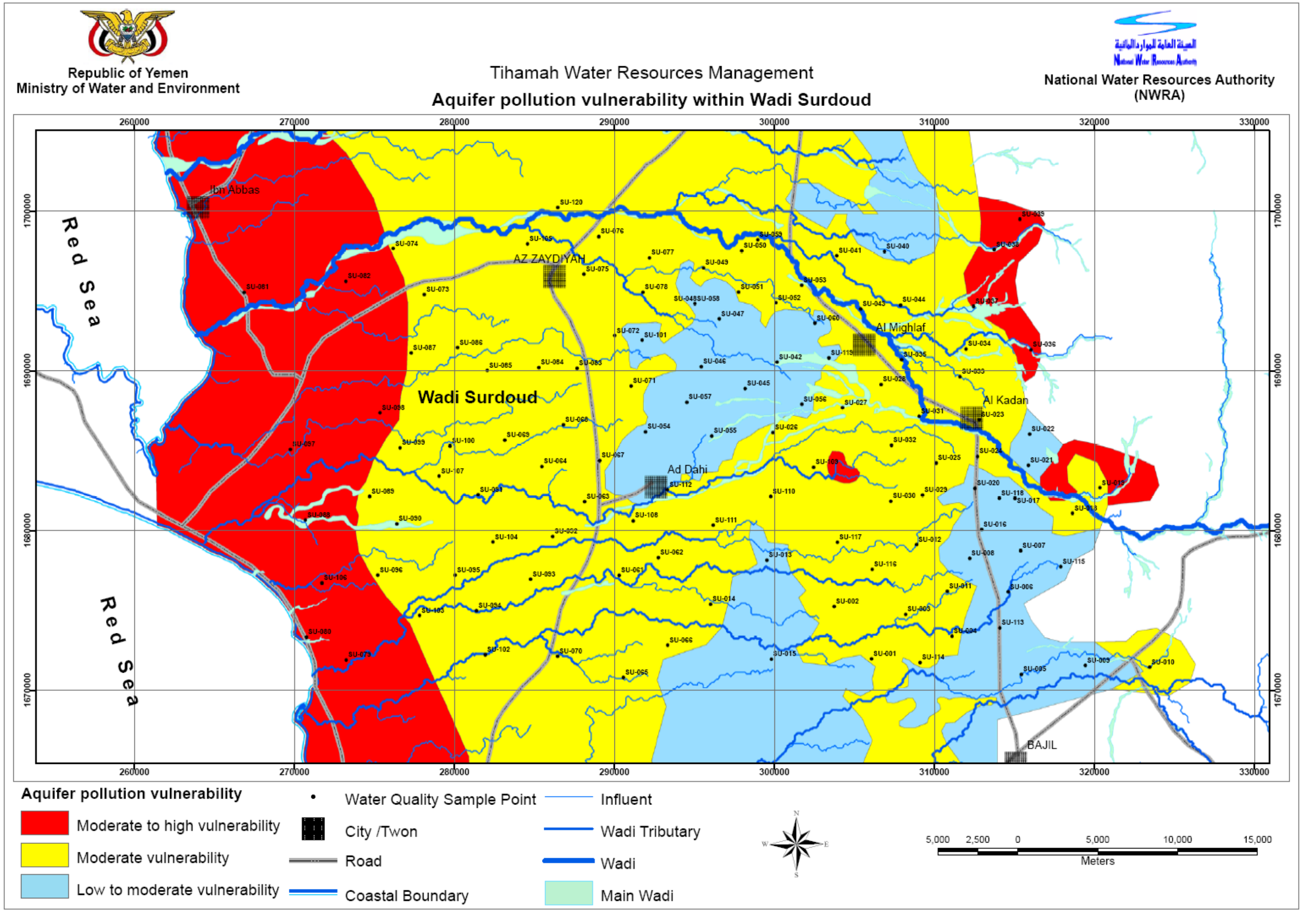
This type is concentrated mainly in the mid stream with small part in east ant south of the upstream with average depth to water of 55 m and according to the equation:

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 27: Aquifer pollution vulnerability of the study area



6- Conclusion and Recomendation

- From the 3279 operational water points were inventoried in Wadi Surdud in 2008, well inventory, 121 water samples collected from dug and drill wells in the wadi during January 5, 2008 – February 1, 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 to found two types of chemical water types in the study area {Indiscriminate Ions and (Na+K)(SO_4+Cl)}. These types of water concentrated in the upstream and down stream respectively. This means that there is no recharge in the upstream, at least during the last few years. The high concentration of Na & Cl in the down stream side indicates that this area is affected by the salt water intrusion to the groundwater.
- According to the evaluation of the watr samples, about 74% of the supply wells are classified as unsuitable for drinking water, and only 26 % of these wells do not exceed the Yemeni standard for drinking water
- Only 5 water samples were unsuitable for irrigation because of very high salinity and very high sodium hazard, while 22 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 Surdud 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 the Wadi especially in Al Marba'a, A'azan, Al Monirah, Dir Omer, Kadaf, Dar Da'am and Dir

Al Kaderi villages should be change because it were have a high concentration of nitrate

- we recommend to collect water samples from supply and domestic wells in the wadi 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 I: Technical staff who participated in the Study

1. Eng./ Ali Kasem As Sayagh (NWRA-HQ)	Study Supervisor
2. Eng./ Mohamed Emad	GIS Expert
3. 3Eng./ Walid Al Haidary (NWRA-Hodaidah branch	Sample collector
4. Eng./ Ahmed Al Wasabi (TDA-Hodeidah)	Sample collector
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6. Eng./ Ahmed Sa'aid Kaid	Chemist (TDA Laboratory)
7. Eng./ Abdunnaser Taresh	Chemist (TDA Laboratory)
8. Eng./Amin Gohan	Chemist (TDA Laboratory)
9. Eng./Nadia Al Arami	Chemist (TDA Laboratory)
10. Eng./ Ashwaq Arragmi	Chemist (TDA Laboratory)

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
Su-001	A-0230	Al Marba'	Dug/ Bore	306091	1671964	50	Supply
Su-002	A-0265	Al Swajdah	Dug	303745	1675236	43	Irrigation
Su-003	A-0205	Mahal Al Haij	Dug	308214	1674734	43.5	Irrigation
Su-004	A-0162	Al Nabaqah	Dug/ Bore	311114	1673375	100	Irrigation
Su-005	A-0066	Dihnat	Borehole	315455	1670991	100	Irrigation
Su-006	A-0101	Dihnat	Borehole	314626	1676150		Irrigation
Su-007	B-0140	Al Qadheeb	Borehole	315402	1678732	90.00	Irrigation
Su-008	B-0188	Al Mazbal	Dug	312214	1678246	65.00	Irrigation
Su-009	A-0033	Dihnat	Borehole	319444	1671549	100.00	Irrigation
Su-010	A-0004	A'azan	Dug/ Bore	323470	1671427	69.00	Supply
Su-011	A-0177	Deir Gaber	Dug/ Bore	310820	1676200	90.00	Irrigation
Su-012	B-0248	Bani Maqbool	Borehole	308901	1679112	80.00	Irrigation
Su-013	H-0006	Al kh ghrua	Dug	299551	1678127	55.00	Irrigation
Su-014	H-0069	Mahl mahmmed Saeed	Dug/ Bore	296023	1675382	65.00	Supply
Su-015	H-0058	Al gadida	Dug/ Bore	299818	1671940	115.00	Supply
Su-016	B-0127	Al Ashraf	Borehole	312968	1680054	80.00	Irrigation
Su-017	B-0066	Al Jelh	Borehole	315057	1682006	120.00	Irrigation
Su-018	B-0052	Al High	Dug	318647	1681068	48.70	Irrigation
Su-019	B-0006	Thowb Bani mahal	Dug	320364	1682667	43.70	Domastic
Su-020	B-0220	Al Ashraf	Borehole	312549	1682630	100.00	Irrigation
Su-021	B-0016	Mahall alshikh	Borehole	315883	1684075	102.00	Supply
Su-022	B-0024	Al Zouih	Dug/ Bore	315968	1686033	97.00	Irrigation
Su-023	C-0167	Al Kadan	Borehole	312820	1686925	80.00	Supply
Su-024	B-0234	Al Nassery	Dug/ Bore	312709	1684629	81.00	Supply
Su-025	B-0305	As Sarh	Dug/ Bore	310118	1684219	66.00	Irrigation
Su-026	F-0237	Deer Harsh	Borehole	299927	1686126	100.00	Irrigation
Su-027	C-0367	Adhobea	Borehole	304266	1687671	80.00	Irrigation
Su-028	C-0260	Al Herthah	Borehole	306677	1689130	40.00	Domastic

Sample No.	Well No.	Site	Well Type	UTM East	UTM North	Total Depth (m)	Water Use
Su-029	B-0310	As Sarh	Borehole	309272	1682202	80.00	Irrigation
Su-030	B-0323	Al Saied Mohammed	Dug	307296	1681833	32.90	Supply
Su-031	C-0201	Al Muqannaf	Borehole	309061	1687156	80.00	Irrigation
Su-032	C-0314	Al Garabehh	Borehole	307332	1685325	80.00	Irrigation
Su-033	C-0096	Al Bgosh	Borehole	311610	1689633	70.00	Irrigation
Su-034	C-0004	Al Ghazarah	Borehole	311990	1691363	62.00	Irrigation
Su-035	C-0054	Al Kried	Borehole	307965	1690695	90.00	Irrigation
Su-036	C-0108	Al Hawdh	Spring	316051	1691306	7.60	Irrigation
Su-037	D-0014	Al Maqana'a	Dug	312466	1694029	25.55	Domastic
Su-038	D-0010	Al Ma'azebah	Dug	313758	1697576	9.80	Domastic
Su-039		Al Hawan	Dug	315357	1699489		Domastic
Su-040	D-0025	Al Minwab	Borehole	306895	1697460	80.00	Irrigation
Su-041	D-0052	Al Jabaliah	Borehole	303916	1697202	90.00	Irrigation
Su-042	F-0177	Al sharih	Borehole	300183	1690541	70.00	Irrigation
Su-043	D-0071	Al Minwab	Borehole	305406	1693877	80.00	Irrigation
Su-044	D-0082	Al Minwab	Borehole	307897	1694106	90.00	Irrigation
Su-045	F-0193	Hothekani	Borehole	298184	1688864	120.00	Irrigation
Su-046	F-0165	Atalebi	Borehole	295441	1690255	110.00	Irrigation
Su-047	D-0233	Dier Al Wajiyah	Dug/ Bore	296576	1693240	100.00	Irrigation
Su-048	E-0019	Dir Harazi	Dug/ Bore	295047	1694185	63.00	Irrigation
Su-049	D-0210	Deir al Haraze	Dug/ Bore	295584	1696432	80.00	Irrigation
Su-050	D-0168	Deir Muhde	Borehole	297970	1697493	70.00	Irrigation
Su-051	D-0174	Dar Da'aam	Dug/ Bore	297784	1694928	95.00	Supply
Su-052	D-0156	Al Kidf	Borehole	300115	1694254	75.00	Irrigation
Su-053	D-0326	Al Masha'aleah	Dug/ Bore	301717	1695342	80.00	Irrigation
Su-054	H-0419	Al Qu paiah	Dug/ Bore	291969	1686182	64.50	Irrigation
Su-055	H-0465	Al MesKa	Dug/ Bore	296107	1685914	90.00	Irrigation
Su-056	C-0415	Al Mwahebah	Borehole	301723	1687903	98.00	Supply
Su-057	E-0353	Al Marofia	Dug/ Bore	294535	1688021	77.00	Irrigation
Su-058	E-0019	Dir Harazi	Dug/ Bore	295047	1694185	130.00	Irrigation
Su-059	D-0167	Al Muqazila	Borehole	298967	1698199	70.00	Irrigation

Sample No.	Well No.	Site	Well Type	UTM East	UTM North	Total Depth (m)	Water Use
Su-060	D-0319	Al Haddadiyah	Borehole	302541	1692980	85.00	Irrigation
Su-061	H-0100	Bokia	Borehole	290312	1677179	100.00	Irrigation
Su-062	H-0078	Al Kadri	Borehole	292765	1678284	105.00	Irrigation
Su-063	H-0186	Dir Salam	Dug/ Bore	288159	1681809	60.00	Supply
Su-064	H-0212		Borehole	285489	1684009	70.00	Irrigation
Su-065	H-0105	Uwns	Borehole	290575	1670797	80.00	Irrigation
Su-066	H-0082	salimia	Dug/ Bore	293348	1672812	80.00	Supply
Su-067	H-0269	Kadaf	Dug/ Bore	289091	1684364	60.00	Supply
Su-068	H-0230	Al Mahel	Borehole	286827	1686612	53.00	Irrigation
Su-069	H-0298	Deer Al bahri	Borehole	283163	1685644	100.00	Supply
Su-070	H-0114	yakeni	Borehole	286458	1672133	60.00	Irrigation
Su-071	E-0186	Al Marofia	Borehole	291057	1689036	83.00	Supply
Su-072	E-0153	Al Mashaf	Borehole	290032	1692194	97.00	Supply
Su-073	F-0049	moniera	Borehole	278139	1694773	60.00	Supply
Su-074	F-0037	Edris	Borehole	276196	1697641	30.00	Irrigation
Su-075	E-0176	Al Zedia	Borehole	288113	1696054	60.00	Irrigation
Su-076	E-0095	Zudia	Borehole	289047	1698392	100.00	Irrigation
Su-077	E-0078	Zhafr	Borehole	292206	1697064	60.00	Irrigation
Su-078	E-0063	Rbat	Borehole	291802	1694917	60.00	Supply
Su-079	G-0011	Al Org	Borehole	273255	1671886	30.00	Irrigation
Su-080	G-0001	Al Org	Borehole	270762	1673308	31.00	Supply
Su-081	F-0006	Al haronia	Dug	266879	1694901	5.58	Domastic
Su-082	F-0027	AL kashri	Dug	273232	1695592	47.00	Irrigation
Su-083	F-0126	Dir Aomer	Borehole	287686	1690136	66.00	Supply
Su-084	F-0109	hashabra	Dug/ Bore	285294	1690184	75.40	Supply
Su-085	F-0100	Kadri	Dug	282071	1690006	40.50	Supply
Su-086	F-0094	Hard	Borehole	280222	1691446	105.00	Supply
Su-087	F-0061	Arid	Dug/ Bore	277316	1691110	53.45	Supply
Su-088	G-0220	Al Grb Mahee Alakel	Dug/ Bore	270705	1680646	30.00	Irrigation
Su-089	G-0286	Mahel AL koa	Borehole	274713	1682124	55.00	Supply
Su-090	G-0250	Aglani	Borehole	276413	1680408	42.00	Irrigation

Sample No.	Well No.	Site	Well Type	UTM East	UTM North	Total Depth (m)	Water Use
Su-091	H-0339	Bani Al shashoa	Borehole	281493	1682229	58.00	Irrigation
Su-092	H-0166	Dir Shoel	Borehole	286162	1679624	50.00	Irrigation
Su-093	H-0125	Al dbarsh	Borehole	284780	1676947	40.00	Supply
Su-094	G-0065	Al Org	Dug/ Bore	281397	1674974	42.00	Irrigation
Su-095	G-0164	Kalia	Borehole	280061	1677196	48.00	Irrigation
Su-096	G-0157	Kalia	Borehole	275228	1677191	45.00	Irrigation
Su-097	G-0122	Al sheli	Borehole	269761	1685066	45.00	Irrigation
Su-098	F-0084	Sanfia	Dug	275363	1687367	25.40	Irrigation
Su-099	G-0354	Al Orsh	Borehole	276624	1685171	50.00	Irrigation
Su-100	H-0383	Al Orsh	Borehole	279741	1685291	50.00	Irrigation
Su-101	E-0144	Dir Aslei	Dug/ Bore	291753	1691911	70.00	Supply
Su-102	G-0079	Al Org	Borehole	281941	1672218	70.00	Irrigation
Su-103	G-0090	Al koalia	Dug/ Bore	277836	1674669	42.00	Irrigation
Su-104	H-0355	Aglani	Dug/ Bore	282425	1679278	49.00	Irrigation
Su-105	E-0327	Mahel Zoma	Dug/ Bore	284582	1697933	45.00	Irrigation
Su-106	G-0098	Gabria	Dug/ Bore	271740	1676702	28.70	Irrigation
Su-107	G-0315	Deer Kozi	Dug/ Bore	279064	1683398	55.00	Irrigation
Su-108	H-0093	Gahter	Dug/ Bore	291188	1680605	80.00	Irrigation
Su-109	174	Al Gerfah	Dug/ Bore	302472	1683958		Irrigation
Su-110	G-0414	Al Mohaisem	Borehole	299784	1682124	70.00	Irrigation
Su-111	H-0476	Al Sahly	Dug/ Bore	296187	1680322	65.00	Irrigation
Su-112	F-0379	Al Gathim	Dug/ Bore	293337	1682549	69.00	Irrigation
Su-113	A-0085	Dihnat	Dug	314094	1673895	75.00	Irrigation
Su-114	A-0150	Al Merian	Dug	309125	1671724	50.00	Irrigation
Su-115	B-0034	Al Jubirih	Dug/ Bore	317909	1677729	70.00	Irrigation
Su-116	B-0408	Al Nageah	Dug	306124	1677567	44.50	Irrigation
Su-117	B-0443	Al Qobeah	Dug	303951	1679255	28.30	Domastic
Su-118	B-0086	Al Jelh	Dug/ Bore	314075	1682025	70.00	Irrigation
Su-119	C-0528	Mahl Ali Omer	Borehole	303416	1690796	100.00	Irrigation
Su-120	E-0437	Deer Al Zueh	Borehole	286483	1700223	68.00	Supply

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
SU-001	1930	7.4	1235	2.98	86	26	290	8.2	0.37	266	67	580	Nil	51	1.48	7.0	160	324
SU-002	1365	7.5	874	2.60	74	18	191	4.13	0.39	153	86.4	427	Nil	30	1.311	5.2	180	261
SU-003	1489	7.2	953	2.40	60	29	191	7.2	0.50	106.5	96	549	Nil	51.1	1.25	5.1	380	272
SU-004	2040	6.4	1306	0.93	20	139	177	4.3	0.44	177.5	125	732	Nil	45.3	1.16	3.1	560	634
SU-005	1870	7.4	1206	2.13	120	35	221	7.7	0.39	355	110	366	Nil	19.59	1.58	4.6	120	447
SU-006	1090	7.6	698	1.40	56	30	127	4.1	0.44	142	67	305	Nil	27.96	0.912	3.4	140	266
SU-007	955	7.8	611	2.60	52	20	117	5.3	0.67	89	58	305	Nil	48.98	0.806	3.5	160	214
SU-008	1053	7.7	685	2.92	46	28	133	4.9	0.56	106.5	48	366	Nil	29.95	0.889	3.8	160	233
SU-009	1960	7.5	1248	2.14	80	40	276	9.8	0.61	319.5	115	457.5	Nil	37.88	1.7	6.3	200	368
SU-010	1719	7.5	1100	1.88	60	36	253	7.8	0.36	284	106	366	Nil	56.2	1.6	6.4	160	301
SU-011	1404	6.5	908	2.27	96	23	166	5.9	0.36	85	96	549	Nil	34	1.7	3.9	320	337
SU-012	911	7.6	592	3.02	60	17	106	3.9	0.36	78	48	336	Nil	23	0.78	3.1	160	221
SU-013	1365	7.5	874	2.07	70	22	189	5.7	0.39	142	86	427	Nil	48	1.16	5.0	200	267
SU-014	1287	7.8	832	2.42	56	26	177	6.01	0.39	142	96	366	Nil	49	1.27	4.9	180	249
SU-015	1910	7.5	1222	0.85	96	41	244	9.01	0.39	302	130	427	Nil	49	2.0	5.2	140	412
SU-016	931	7.8	596	2.74	60	23	99	3.5	0.41	89	48	305	Nil	45	1.39	2.8	140	247
SU-017	993	7.5	636	1.78	64	22	110	4.06	0.45	107	58	305	Nil	43	0.84	3.0	120	252

Sample No.	E.C	pH	TDS	DO	Ca	Mg	Na	K	Fe	Cl	So4	Hco3	Co3	No3	F	SAR	TA	TH
SU-018	885	7.6	566	3.15	52	17	108	5.7	0.41	75	48	305	Nil	44	0.75	3.3	140	201
SU-019	1910	6.4	1222	1.52	122	30	237	7.7	0.46	107	106	793	Nil	49	1.62	5.0	560	431
SU-020	987	7.5	632	2.57	66	11	127	4.72	0.45	117	48	305	Nil	31	1.32	3.8	140	211
SU-021	1292	7.4	827	2.29	100	8.4	163	3.3	0.46	142	115	366	Nil	28.52	1.14	4.2	220	285
SU-022	4830	6.9	3091	1.13	500	150	244	8.0	0.53	1260.3	192	488	Nil	44.02	0.648	2.5	200	1880
SU-023	813	7.6	520	2.22	50	18	94.3	1.7	0.59	71.0	48	305	Nil	6.51	0.45	2.9	160	201
SU-024	984	7.5	630	1.92	62	17	120	2.5	0.49	106.5	57.6	305	Nil	34.162	1.71	3.5	160	226
SU-025	922	7.7	596	2.17	60	7.2	127	3.3	0.52	78	48	336	Nil	31.0	0.78	4.1	160	180
SU-026	1707	7.5	1093	1.65	50	42	253	2.5	0.52	249	106	427	Nil	48.0	1.81	6.4	240	301
SU-027	1805	7.3	1155	2.57	88	35	246	1.7	0.52	213	115	549	Nil	36	1.22	5.6	200	367
SU-028	2000	7.2	1280	1.88	74	83	214	3.3	0.55	249	125	610	Nil	25	0.72	4.0	320	534
SU-029	948	7.6	607	2.93	54	8.4	138	2.5	0.55	107	48	305	Nil	28	0.49	4.6	180	170
SU-030	1081	7.7	692	2.92	58	18	147	0.6	0.50	124	67	305	Nil	53	0.92	4.3	160	221
SU-031	1246	7.5	797.4	2.12	80	17	161	1.7	0.56	71	58	543	Nil	19	1.05	4.3	340	271
SU-032	965	7.5	618	2.43	56	14.4	129	1.7	0.62	89	48	354	Nil	19	0.82	4.0	180	200.5
SU-033	1808	7.3	1157	2.92	122	11	253	2.5	0.62	249	106	500	Nil	33	2.30	5.9	220	351
SU-034	2520	6.9	1617	1.96	210	24	285	9.8	0.63	462	120	549	Nil	40	1.04	5.0	260	626
SU-035	1886	7.3	1207	2.33	60	60	246	5.1	0.62	160	120	671	Nil	50	1.20	5.4	240	402

Sample No.	E.C	pH	TDS	DO	Ca	Mg	Na	K	Fe	Cl	So4	Hco3	Co3	No3	F	SAR	TA	TH
SU-036	1160	7.5	742	1.73	68	14.4	159	3.3	0.62	107	58	427	Nil	25	0.40	4.5	220	230
SU-037	2520	7.4	1613	2.31	64	40	428	3.5	0.62	426	154	555	Nil	52	0.97	10.3	260	328
SU-038	896	7.2	573.4	2.20	54	7.2	129	1.7	0.62	53	48	366	Nil	28	0.29	4.4	160	165
SU-039	1261	7.6	813	1.86	10	12	253	3.3	0.67	71	67	531	Nil	29	0.91	12.7	300	75.4
SU-040	1910	6.9	1222.4	1.17	76	30	292	2.5	0.62	320	115	427	Nil	40	1.48	7.2	240	316
SU-041	1870	7.1	1197	1.35	160	8.4	228	3.3	0.62	291	106	458	Nil	44	1.58	4.7	280	435
SU-042	1620	7.3	1037	3.34	90	29	212	2.5	0.58	178	96	500	Nil	57	1.37	4.9	240	347
SU-043	2040	7.4	1306	1.18	190	42	168	3.3	0.50	344	125	439	Nil	50	1.73	2.9	220	651
SU-044	2090	6.9	1338	1.29	172	41	202	1.7	0.46	327	125	519	Nil	31	1.77	3.6	280	602
SU-045	1636	7.1	1047	3.07	24	62	228	2.1	0.52	160	96	549	Nil	49	1.39	5.5	260	320
SU-046	1210	7.5	774	2.20	26	46	159	2.5	0.55	142	67	378	Nil	28	1.03	4.3	200	258
SU-047	1170	7.2	749	1.73	34	41	150	3.3	0.57	107	58	427	Nil	28	0.99	4.0	240	257
SU-048	1430	7.2	915	2.12	22	60	189	1.7	0.55	160	86	458	Nil	27	1.19	4.7	200	307
SU-049	1789	7.2	1145	1.50	40	48	271	2.5	0.45	213	96	549	Nil	50	1.50	6.8	240	302
SU-050	1320	7.1	845	1.10	20	52	179	3.3	0.53	110	96	458	Nil	34	1.11	4.8	260	268
SU-051	1470	7.1	941	1.34	116	9.6	184	3.3	0.57	202	82	384	Nil	59	1.46	4.4	240	330
SU-052	1430	7.1	922.4		114	24	150	3.3	0.54	185	86	384	Nil	57	1.64	3.3	280	386
SU-053	1420	7.1	909	1.23	100	24	163	2.5	0.52	178	96	384	Nil	49	1.82	3.8	260	351

Sample No.	E.C	pH	TDS	DO	Ca	Mg	Na	K	Fe	Cl	So4	Hco3	Co3	No3	F	SAR	TA	TH
SU-054	1700	7.1	1088	0.87	80	48	207	3.3	0.46	249	96	445	Nil	37	1.82	4.5	280	402
SU-055	1710	7.2	1094	1.16	68	37	242	2.5	0.52	227	96	488	Nil	40	1.24	5.8	260	325
SU-056	1520	7.2	973	1.18	128	31	140	3.3	0.48	231	86	366	Nil	51	1.0	2.9	220	450
SU-057	1740	7.1	1114	1.59	136	35	175	5.0	0.45	249	106	451	Nil	45	1.25	3.5	280	486
SU-058	1663	7.2	1064	1.53	92	43	193	2.5	0.48	249	96	427	Nil	39	0.57	4.2	260	411
SU-059	1545	7.1	989	0.79	88	26	202	2.5	0.42	178	96	488	Nil	27	0.41	4.8	260	329
SU-060	1752	7.5	1121	0.60	122	12	237	3.3	0.48	249	115	458	Nil	37	0.48	5.5	240	355
SU-061	1271	7.7	813.4	4.10	52	31	170	2.5	0.37	178	91	305	Nil	48	0.73	4.6	180	260
SU-062	1285	8.1	822.4	4.46	68	26	166	2.5	0.38	192	72	305	Nil	56	0.96	4.3	200	279
SU-063	1600	8.0	1024	3.21	40	36	251	2.5	0.033	266	96	366	Nil	30	0.46	6.9	220	251
SU-064	1678	8.0	1074	3.43	50	54	223	2.5	0.39	249	101	427	Nil	40	0.72	5.2	180	352
SU-065	1643	7.9	1052	3.24	80	44	198	3.3	0.043	284	101	354	Nil	30	0.48	4.4	120	385
SU-066	1356	7.9	868	2.46	74	25	177	2.5	0.41	213	86.4	305	Nil	41.79	1.6	4.5	180	290
SU-067	1740	7.9	1114	2.75	44	44.4	262	2.5	0.41	213	110.4	488	Nil	61.01	1.64	6.6	280	295
SU-068	1860	7.9	1190	1.14	84	60	214	2.5	0.42	319.5	96	427	Nil	31.25	1.82	4.3	260	462
SU-069	1705	8.4	1091	1.15	40	36	276	0.83	0.45	230.7	96	488	Nil	25	1.8	7.8	240	236
SU-070	1344	8.1	860	4.10	64	30	177	1.7	0.42	213	86	305	Nil	34	1.6	4.6	120	276
SU-071	1526	7.9	985	3.12	60	48	189	1.7	0.42	159.7	96	488	Nil	41.2	1.8	4.4	240	352

Sample No.	E.C	pH	TDS	DO	Ca	Mg	Na	K	Fe	Cl	So4	Hco3	Co3	No3	F	SAR	TA	TH
SU-072	1716	7.7	1098	4.06	64	46	232	1.7	0.42	248.5	115	427	Nil	40	2.2	5.4	200	352
SU-073	1930	7.9	1235	2.43	52	60	269	0.83	0.42	309	125	427	Nil	57.2	1.12	6.00	160	382
SU-074	4920	7.9	3149	1.92	42	48	989	3.159	0.42	1136	192	719	Nil	84	1.235	24.6	180	307
SU-075	1774	8.0	1135	4.11	52	47	258	2.5	0.44	284	115	427	Nil	13.95	2.19	6.2	240	327
SU-076	2820	7.5	1805	1.56	88	80	391	2.5	0.45	462	192	659	Nil	20	1.82	7.2	260	556
SU-077	1920	7.9	1229	1.66	90	49	242	2.5	0.44	320	149	366	Nil	59	2.38	5.1	220	432
SU-078	1711	7.8	1095	2.02	82	44	212	2.5	0.44	284	96	397	Nil	32	1.82	4.7	220	391
SU-079	2820	7.9	1805	1.86	40	48	508	1.7	0.47	639	163	366	Nil	45.7	0.67	12.76	160	302
SU-080	2280	8.1	1459	2.29	50	62	345	2.5	0.44	426	134	458	Nil	28.9	0.43	7.64	160	385
SU-081	9750	8.2	6240	2.50	160	19	2185	3.3	0.42	2226	336	1647	Nil	44.14	1.67	86.4	940	480
SU-082	3310	8.8	2118	6.22	28	28	672	3.3	0.46	568	192	671	30	65.4	1.01	21.32	160	188
SU-083	1992	8.1	1275	5.38	40	49	315	2.5	0.44	231	115	230	Nil	60.2	0.93	7.8	240	306
SU-084	1854	8.1	1187	2.27	26	34	331	2.5	0.44	213	106	579.5	Nil	49.6	0.76	10	260	208
SU-085	1808	8.3	1157	2.93	18	26	345	2.5	0.45	213	96	549	Nil	63.74	0.99	12.25	260	509
SU-086	1621	8.1	1037	4.76	34	48	239	2.5	0.44	178	96	519	Nil	41.9	0.65	6.20	180	287
SU-087	3540	7.9	2266	3.78	58	58	635	3.3	0.45	533	192	964	Nil	32.3	1.73	14.1	160	389
SU-088	5140	7.6	3290	1.85	162	163	681	3.3	0.43	1136	240	781	Nil	97	0.68	8.99	120	1090
SU-089	2690	7.7	1722	4.84	92	118	285	3.3	0.47	462	163	610	Nil	27	1.20	4.6	140	726

Sample No.	E.C	pH	TDS	DO	Ca	Mg	Na	K	Fe	Cl	So4	Hco3	Co3	No3	F	SAR	TA	TH
SU-090	3840	7.7	2458	2.61	126	168	414	3.3	0.48	657	182	915	Nil	61.7	2.0	5.65	160	1021
SU-091	1840	8.7	1178	4.01	50	58	253	3.3	0.45	249	96	488	15	52	1.20	5.8	180	369
SU-092	1756	8.0	1124	4.11	26	23	329	2.5	0.44	213	96	549	Nil	33	0.51	11.31	220	162
SU-093	2490	7.7	1594	3.02	68	65	368	3.3	0.46	497	115	488	Nil	27	1.30	7.6	240	443
SU-094	2580	7.7	1651	3.35	94	94	304	3.3	0.48	568	130	366	Nil	60.9	1.43	5.3	180	630
SU-095	2750	7.7	1760	4.67	94	89	352	2.5	0.46	533	134	567	Nil	23.4	0.38	6.2	200	609
SU-096	2810	7.6	1798	1.28	106	112	308	2.5	0.43	657	144	366	Nil	33.9	1.01	4.96	120	735
SU-097	3500	7.9	2240	1.81	30	40	695	1.7	0.46	888	115	427	Nil	35.4	0.55	19.5	240	243
SU-098	3260	8.1	2086	3.40	26	35	651	1.7	0.47	817	154	366	Nil	23.6	0.36	19.5	260	212
SU-099	2730	8.0	1747	1.93	40	36	511	1.7	0.47	604	134	427	Nil	29.5	0.46	14.0	220	251
SU-100	2400	7.7	1536	1.28	44	77	352	1.7	0.48	604	96	275	Nil	29.5	0.46	7.4	220	433
SU-101	1600	8.0	1024	3.90	46	47	225	1.7	0.47	249	96	397	Nil	29.6	0.46	5.6	200	312
SU-102	2070	7.7	1325	2.72	74	72	251	1.7	0.50	355	106	488	Nil	25.8	1.60	4.9	140	487
SU-103	5170	7.5	3309	3.37	148	214	607	3.3	0.47	1420	240	366	Nil	41.3	0.65	7.4	140	1269
SU-104	2210	7.8	1414	2.90	48	55	345	1.7	0.48	426	125	427	Nil	27.6	1.04	8.0	200	351
SU-105	2360	7.7	1510	2.24	44	55	384	3.3	0.47	426	115	519	Nil	43.2	0.065	9.0	260	341
SU-106	3530	7.6	2259	2.40	90	108	499	2.5	0.49	905	144	366	Nil	47.2	0.72	8.4	140	679
SU-107	2330	7.8	1491	1.62	68	103	258	1.7	0.46	462	96	488	Nil	17.4	0.274	4.6	160	603

Sample No.	E.C	pH	TDS	DO	Ca	Mg	Na	K	Fe	Cl	So4	Hco3	Co3	No3	F	SAR	TA	TH
SU-108	1860	7.6	1190	2.63	36	32	322	2.5	0.50	355	96	366	Nil	35.4	0.55	9.3	200	224
SU-109	1980	7.5	1267	1.94	72	47	281	4.2	0.52	320	96	488	Nil	47.2	0.72	6.3	200	377
SU-110	1281	7.5	820	1.96	60	19	186	2.5	0.51	142	96	366	Nil	47.8	0.74	5.3	220	230
SU-111	1727	7.5	1105	2.19	72	41	235	3.3	0.48	231	192	366	Nil	45	0.70	5.5	160	352
SU-112	1389	7.5	889	2.21	54	29	200	3.3	0.51	178	96	366	Nil	52.5	0.82	5.4	160	257
SU-113	2030	7.3	1299	2.65	140	36	235	5.0	0.50	391	96	427	Nil	15.9	0.27	4.6	160	501
SU-114	1900	7.4	1216	3.31	140	36	205	3.3	0.48	355	106	366	Nil	47.2	0.722	4.0	120	501
SU-115	2560	7.3	1638	2.55	220	53	232	2.5	0.53	462	125	549	Nil	59.02	0.912	3.6	220	773
SU-116	958	7.6	613	2.91	52	18	124	3.3	0.50	82	96	305	Nil	16.6	0.255	3.8	160	206
SU-117	1415	7.3	906	1.28	74	30	182	3.3	0.47	178.0	125	366	Nil	32.5	0.49	4.5	180	311
SU-118	985	7.5	630	3.41	58	23	115	1.7	0.50	96	77	305	Nil	32.49	0.50	3.2	140	242
SU-119	1455	7.3	931	1.20	74	31	189	2.5	0.49	160	115	427	Nil	38.4	0.59	4.6	220	315
SU-120	2550	7.3	1632	0.81	54	66	396	2.5	0.50	444	120	610	Nil	29.5	0.46	8.5	220	412

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
SU-001	19.3	19.30	0.01	1929	1930	0.01	1144.05	1235	1.08
SU-002	13.6	13.66	0.17	1364	1365	0.04	814.431	874	1.07
SU-003	13.9	14.89	3.39	1440	1489	1.67	871.95	953	1.09
SU-004	20.4	20.40	0.00	2040	2040	0.01	1128.9	1306	1.16
SU-005	18.7	18.70	-0.08	1871	1870	-0.04	1090.26	1206	1.11
SU-006	10.9	10.89	-0.08	1090	1090	-0.02	637.912	698	1.09
SU-007	9.5	9.55	0.24	952	955	0.13	574.756	611	1.06
SU-008	10.6	10.53	-0.10	1054	1053	-0.05	617.399	685	1.11
SU-009	19.6	19.60	0.00	1960	1960	0.01	1154.99	1248	1.08
SU-010	17.2	17.20	-0.02	1720	1719	-0.04	1024.56	1100	1.07
SU-011	14.1	14.03	-0.21	1406	1404	-0.08	837.36	908	1.08
SU-012	9.1	9.12	-0.08	912	911	-0.08	538.64	592	1.10
SU-013	13.7	13.63	-0.28	1367	1365	-0.06	820.45	874	1.07
SU-014	12.8	12.86	0.13	1284	1287	0.12	773.27	832	1.08
SU-015	19.1	19.11	0.12	1909	1910	0.03	1129.6	1222	1.08
SU-016	9.3	9.31	-0.06	931	931	-0.01	552.3	596	1.08
SU-017	9.9	9.96	0.16	994	993	-0.07	592.35	636	1.07
SU-018	8.9	8.86	-0.02	886	885	-0.08	533.86	566	1.06
SU-019	19.1	19.10	-0.03	1910	1910	-0.01	1136.58	1222	1.08
SU-020	9.9	9.87	-0.01	987	987	0.02	589.49	632	1.07

SU-021	12.9	12.92	0.16	1290	1292	0.08	781.62	827	1.06
SU-022	48.3	48.24	-0.08	4828	4830	0.02	2692.248	3091	1.15
SU-023	8.2	8.13	-0.16	814	813	-0.07	473.55	520	1.10
SU-024	9.8	9.84	0.17	982	984	0.08	584.962	630	1.08
SU-025	9.2	9.25	0.17	923	922	-0.06	557.4	596	1.07
SU-026	17.1	17.09	0.05	1708	1707	-0.04	1009.03	1093	1.08
SU-027	18.1	18.04	-0.07	1805	1805	-0.01	1065.84	1155	1.08
SU-028	20.0	20.06	0.11	2004	2000	-0.09	1140.57	1280	1.12
SU-029	9.5	9.49	0.09	948	948	-0.01	569.94	607	1.07
SU-030	10.8	10.79	-0.11	1080	1081	0.03	652.02	692	1.06
SU-031	12.5	12.47	0.01	1247	1246	-0.04	735.11	797.4	1.08
SU-032	9.7	9.66	-0.02	966	965	-0.06	570.94	618	1.08
SU-033	18.1	18.07	-0.05	1808	1808	-0.01	1079.42	1157	1.07
SU-034	25.2	25.21	0.12	2518	2520	0.03	1481.87	1617	1.09
SU-035	18.8	18.88	0.10	1886	1886	0.01	1105.52	1207	1.09
SU-036	11.6	11.65	0.16	1163	1160	-0.12	691.92	742	1.07
SU-037	25.2	25.20	-0.09	2522	2520	-0.04	1502.09	1613	1.07
SU-038	9.0	8.96	-0.02	896	896	-0.01	541.41	573.4	1.06
SU-039	12.6	12.62	0.08	1261	1261	0.01	765.48	813	1.06
SU-040	19.1	19.13	0.16	1910	1910	0.00	1133.8	1222.4	1.08
SU-041	18.7	18.71	-0.01	1871	1870	-0.02	1117.7	1197	1.07
SU-042	16.2	16.20	-0.02	1621	1620	-0.02	966.45	1037	1.07
SU-043	20.4	20.39	-0.02	2039	2040	0.02	1187.93	1306	1.10
SU-044	20.9	20.92	0.16	2088	2090	0.04	1213.33	1338	1.10
SU-045	16.3	16.37	0.08	1636	1636	0.01	952.41	1047	1.10
SU-046	12.1	12.10	-0.09	1211	1210	-0.04	698.88	774	1.11

SU-047	11.7	11.73	-0.03	1173	1170	-0.13	679.06	749	1.10
SU-048	14.4	14.31	-0.23	1434	1430	-0.13	822.24	915	1.11
SU-049	17.9	17.89	0.09	1787	1789	0.06	1051.85	1145	1.09
SU-050	13.2	13.21	0.01	1321	1320	-0.04	770.74	845	1.10
SU-051	14.7	14.72	0.09	1471	1470	-0.03	888.33	941	1.06
SU-052	14.3	14.30	-0.04	1431	1430	-0.03	851.88	922.4	1.08
SU-053	14.2	14.20	0.12	1418	1420	0.08	845.24	909	1.08
SU-054	17.1	17.00	-0.27	1705	1700	-0.14	989.58	1088	1.10
SU-055	17.1	17.10	0.08	1709	1710	0.02	1007.06	1094	1.09
SU-056	15.2	15.17	0.03	1517	1520	0.10	891.38	973	1.09
SU-057	17.5	17.41	-0.16	1743	1740	-0.10	1023.3	1114	1.09
SU-058	16.6	16.67	0.08	1666	1663	-0.09	971.75	1064	1.09
SU-059	15.4	15.47	0.16	1545	1545	0.01	913.13	989	1.08
SU-060	17.5	17.54	0.12	1752	1752	0.00	1051.06	1121	1.07
SU-061	12.6	12.72	0.30	1268	1271	0.10	756.6	813.4	1.08
SU-062	12.9	12.86	0.03	1286	1285	-0.03	766.84	822.4	1.07
SU-063	16.0	16.00	0.07	1599	1600	0.03	941.593	1024	1.09
SU-064	16.8	16.80	0.10	1678	1678	-0.01	976.81	1074	1.10
SU-065	16.4	16.42	0.17	1639	1643	0.13	953.223	1052	1.10
SU-066	13.6	13.56	0.03	1355	1356	0.02	804.7	868	1.08
SU-067	17.4	17.37	0.00	1737	1740	0.08	1032.36	1114	1.08
SU-068	18.6	18.60	0.06	1859	1860	0.03	1065.69	1190	1.12
SU-069	17.0	17.00	-0.10	1701	1705	0.11	999.58	1091	1.09
SU-070	13.4	13.43	-0.05	1344	1344	0.00	791.12	860	1.09
SU-071	15.3	15.26	-0.03	1526	1526	-0.01	890.62	985	1.11
SU-072	17.2	17.16	-0.04	1716	1716	-0.01	1006.02	1098	1.09

SU-073	19.3	19.29	-0.09	1931	1930	-0.02	1130.77	1235	1.09
SU-074	49.2	49.21	0.02	4920	4920	0.00	2927.214	3149	1.08
SU-075	17.8	17.74	-0.20	1777	1774	-0.09	1031.28	1135	1.10
SU-076	28.1	28.24	0.17	2819	2820	0.02	1633.17	1805	1.11
SU-077	19.2	19.20	0.05	1919	1920	0.04	1133.92	1229	1.08
SU-078	17.1	17.12	0.19	1709	1711	0.06	992.96	1095	1.10
SU-079	28.1	28.17	0.05	2815	2820	0.08	1666.14	1805	1.08
SU-080	22.7	22.79	0.11	2276	2280	0.08	1324.07	1459	1.10
SU-081	104.7	97.50	-3.55	10109	9750	-1.81	5963.73	6240	1.05
SU-082	33.0	33.11	0.10	3308	3310	0.04	1990.77	2118	1.06
SU-083	19.9	18.92	-2.39	1939	1992	1.36	1143.47	1275	1.12
SU-084	18.6	18.55	-0.13	1857	1854	-0.09	1111	1187	1.07
SU-085	18.1	18.08	-0.16	1811	1808	-0.08	1095.08	1157	1.06
SU-086	16.2	16.23	0.21	1620	1621	0.04	951.89	1037	1.09
SU-087	35.4	35.43	-0.01	3543	3540	-0.05	2092.18	2266	1.08
SU-088	51.4	51.40	0.02	5139	5140	0.01	2952.01	3290	1.11
SU-089	26.9	26.91	-0.02	2691	2690	-0.02	1517.97	1722	1.13
SU-090	38.4	38.40	0.01	3840	3840	0.01	2163.48	2458	1.14
SU-091	18.4	18.42	-0.03	1842	1840	-0.06	1070.75	1178	1.10
SU-092	17.6	17.56	-0.10	1758	1756	-0.05	1052.85	1124	1.07
SU-093	24.9	24.90	-0.02	2490	2490	-0.01	1437.86	1594	1.11
SU-094	25.8	25.77	-0.15	2580	2580	-0.01	1475.71	1651	1.12
SU-095	27.5	27.50	0.01	2750	2750	0.01	1568.94	1760	1.12
SU-096	28.1	28.11	0.02	2810	2810	0.00	1584.44	1798	1.13
SU-097	35.1	35.01	-0.13	3506	3500	-0.08	2062.31	2240	1.09
SU-098	32.6	32.62	0.08	3260	3260	0.00	1928.73	2086	1.08

SU-099	27.3	27.31	0.07	2729	2730	0.02	1613.33	1747	1.08
SU-100	24.0	24.02	0.10	2400	2400	0.00	1370.14	1536	1.12
SU-101	16.1	16.02	-0.09	1604	1600	-0.12	933.43	1024	1.10
SU-102	20.7	20.71	0.10	2069	2070	0.03	1180.4	1325	1.12
SU-103	51.7	51.70	-0.02	5171	5170	-0.01	2894.32	3309	1.14
SU-104	22.0	22.10	0.16	2207	2210	0.07	1286.02	1414	1.10
SU-105	23.6	23.60	0.07	2359	2360	0.03	1382.435	1510	1.09
SU-106	35.3	35.29	0.03	3528	3530	0.03	2016.51	2259	1.12
SU-107	23.3	23.31	0.12	2328	2330	0.04	1299.634	1491	1.15
SU-108	18.5	18.60	0.16	1857	1860	0.08	1099.55	1190	1.08
SU-109	19.9	19.81	-0.10	1983	1980	-0.08	1161.44	1267	1.09
SU-110	12.7	12.81	0.26	1278	1281	0.13	774.15	820	1.06
SU-111	17.3	17.28	-0.15	1730	1727	-0.09	1040.53	1105	1.06
SU-112	13.9	13.90	-0.01	1391	1389	-0.05	833.73	889	1.07
SU-113	20.4	20.28	-0.17	2032	2030	-0.05	1175.87	1299	1.10
SU-114	19.0	19.01	0.00	1901	1900	-0.02	1113.302	1216	1.09
SU-115	25.6	25.62	0.08	2560	2560	0.00	1484.362	1638	1.10
SU-116	9.6	9.59	0.03	959	958	-0.04	575.655	613	1.06
SU-117	14.2	14.17	-0.13	1419	1415	-0.13	845.36	906	1.07
SU-118	9.9	9.86	-0.05	986	985	-0.07	587.19	630	1.07
SU-119	14.6	14.55	-0.07	1456	1455	-0.05	867.18	931	1.07
SU-120	25.5	25.51	0.03	2550	2550	0.00	1478.96	1632	1.10