REPUBLIC OF YEMEN

Ministry of Water and Environment

National Water Resources Authority

Wadi Hadhramawt

CHANGES IN GROUNDWATER CHEMISTRY BETWEEN 2001 AND 2011

Sana'a, July 2011

Tel: 01334022 Fax: 01334023 E-Mail: info@nwra-yemen.org Web Site: www.nwrayemen.org

WADI HADHRAMAWT

CHANGES IN GROUNDWATER CHEMISTRY

BETWEEN 2001 AND 2011

National Water Resources Authority (NWRA)

National Program

Integrated Water Resources Management

(NPIWRM)

Compiled by: Victor Rybakov and Ali Kasem As Sayagh

Sana'a, July 2011

SUMMARY

In 2001 KOMEX has carried out a set of technical studies that contributed to better understanding of water quantity and quality in Wadi Hadhramawt which has been selected by NWRA as an important agricultural area with a growing competition between different water sectors. In the framework of the KOMEX's study, a total of 132 water samples have been collected throughout the target area and chemically analyzed. On this basis, the general groundwater chemistry trends and interpretations have been set up to support the formulation of the Water Resources Management Plan for Wadi Hadhramawt. Sampling and analysis conducted by KOMEX have provided a basis for comparison analysis of basic groundwater chemistry. In 2011, the Seyun Branch Office of NWRA has collected a total of 123 water samples which were analyzed in the local chemical laboratory. The results of chemical analysis of the newly collected water samples, summarized in the present report, are compared against the KOMEX's hydrochemical data in order to examine an evolution of groundwater salinity and chemical composition over the last decade.

No significant changes in groundwater salinity patterns are reported between 2001 and 2011 except for an expansion of the elevated salinity areas located in the southern tributary wadis. The expansion of elevated salinity water did not link, however, with a general increase of chloride- and sodium-rich waters in these areas. There is some evidence of a decrease in salinity at the outlet of the main valley east of Tarim that might be explained by an increase of fresh groundwater recharge contributing to the main valley from Wadi Idim, especially due to the heavy flood event reported in 2008.

A lack of a general increase of chloride- and sodium-rich waters in the southern tributary wadis reflects continuation of groundwater recharge along these tributaries while irrigation return flows or other pollution sources did not significantly influence the recharged water. The general pattern of low salinity groundwater is modified when enters the main valley by mixing of different water types and probably by pollution in urban and agricultural lands.

The evolution of HCO_3-rich water to Ca/Mg-SO_4/Cl water between 2001 and 2011 is reported from some wells situated in the main valley, several northern tributaries and in the southern tributary Wadi Idim. This negative environmental trend links very probably to increasing land development (both urban and agricultural) and associated pollution.

In general, salinity of groundwater contained in the sandstone aquifer was reported to remain stable or even slightly decreasing during the last decade. This pattern reflects a stability or increase of fresh groundwater recharge along the tributary wadis between 2001 and 2011. At the same time, an increase of salinity in many locations was observed somewhere in groundwater contained in the shallower alluvium and conglomerate aquifers.

All the analyzed samples show the low sodium hazard for irrigation. At the same time, however, 99% of analyzed samples indicate high (EC = 750-2250 µS/cm) and very high (EC > 2250 µS/cm) salinity hazard to the soil.

None of the samples collected in 2011 from public supply wells were found to be above/higher than the national Maximum Permissible Limits, while most of the samples have concentrations higher than the national Maximum Desirable Limits. One sample, collected from the well owned by the Qawdah Water Supply Project, shows concentrations of almost all major ions higher than those set up as the national Maximum Desirable Limits. In general, the fresh water public wells show rather stable chemical composition in time, likely due to proper borehole design which prevents possible contamination from shallower aquifers.

Despite public wells continue supplying water of reasonable quality, the groundwater protection zones are recommended to establish around the municipal water sources. Adequate land-use restriction measures would be implemented inside these zones to be as large as necessary for a safeguarding the public sources of drinking water and, on the other hand, to be as small as possible for avoiding inadequate inconveniences for neighboring farmers.

The adequate water-quality monitoring network should be upgraded in Wadi Hadhramawt.

A thorough inventory of the potential pollution sources would be carried out throughout the target area with the specific reference to: (a) traditional cess-pits used for domestic and animal wastes; (b) agricultural chemicals applied in the large farms; (c) petrol stations; (d) municipal waste disposals; and (e) oilfield wastes.

It seems that the outputs of the present report will allow deeper development of a general knowledge database related to the hydrochemistry of the target area and provide an additional scientific support for a successful implementation of the Water Resources Management Plan in Wadi Hadhramawt.

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List of Acronyms and Abbreviations

EC	Electrical conductivity (of groundwater)
ID	Identification number
KOMEX	Canadian Consulting Company
masl	Meters above sea level
mbgl	Meters below ground level
meq/l	Milligram equivalents per liter
mg/l	Milligram per liter
MDL	Maximum desirable limit
MPL	Maximum permissible limit
NPIWRM	National Program on Integrated Water Resources Management
NWRA	National Water Resources Authority/ Yemen
NWSA	National Water and Sanitation Authority/Yemen
SAR	Sodium adsorption ratio
TA	Total alkalinity, mg/l
TDS	Total dissolved solids, mg/l
TH	Total hardness, mg/l
UTM	Universal Transverse Mercator
YS	Yemen Standard for Drinking Water

1 INTRODUCTION

Water resources in Yemen are imperiled in many critical basins by overexploitation and pollution. In this context, the National Water Resources Authority (NWRA) has formulated a set of Water Resources Management Plans for the top priority basins with severe water stress and critical water resources management problems. Among other water basins, Wadi Hadhramawt (including main valley and tributary wadis) has been selected by NWRA as an important agricultural area with a growing competition between different water using sectors.

For the sustainable management of limited water resources a sound data basis is crucial, comprising information on hydrology, hydrogeology, geology as well as meteorology, topography and other relevant disciplines. Based on the analysis of available information related to issues relevant for water resources management and in order to cover significant information gaps, KOMEX (2001) has carried out a set of technical studies that contributed to better understanding of water quantity and quality in the target area. In the framework of the KOMEX's study, a total of 132 water samples have been collected throughout the target area and chemically analyzed. On this basis, the general groundwater chemistry trends and interpretations have been set up to support the formulation of the Water Resources Management Plan. Sampling and analysis conducted by KOMEX have provided a basis for further temporal comparison of basic groundwater chemistry.

In 2011, the Seyun Branch Office of NWRA has collected a total of 123 water samples which were analyzed in the local chemical laboratory. The results of chemical analysis of newly collected water samples, summarized in the present report, are compared against the KOMEX's hydrochemical data in order to examine temporal changes in groundwater salinity and chemical composition reported in different parts of Wadi Hadhramawt. It seems that the outputs of the comparison analysis will allow deeper development of a general knowledge database related to the hydrochemistry of the target area and provide an additional scientific support for implementation of the Water Resources Management Plan in Wadi Hadhramawt.

2 LOCATION AND PHYSICAL SETTING OF THE TARGET AREA

The study area is located in the central part of the catchment of Wadi Hadhramawt extending within a strip of land approximately 100 km long and 15 km wide that follows the main wadi valley and also includes the number of its tributary wadis (Figure 1). Administratively, the study area is situated in the central part of the Hadhramawt Governorate.

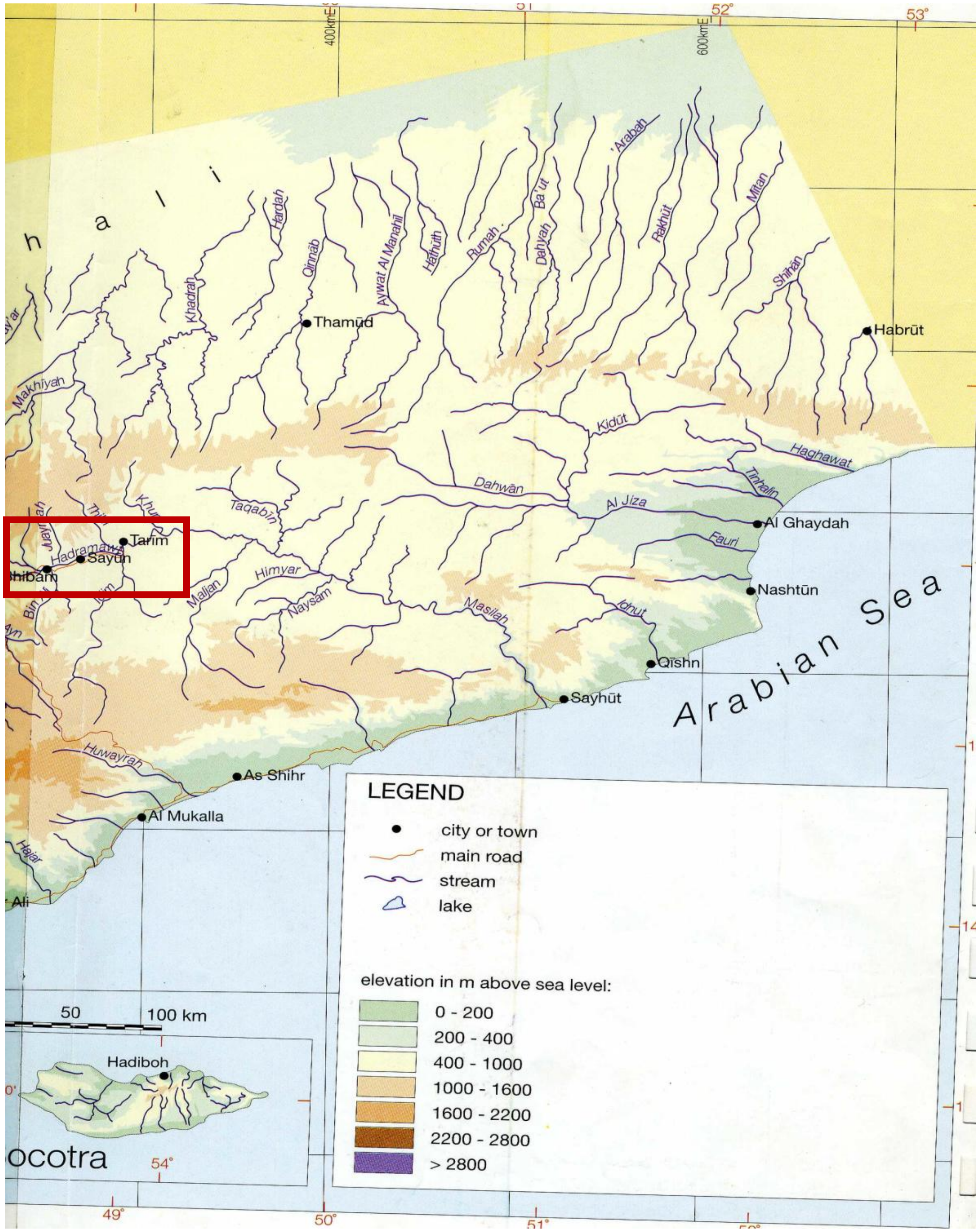

Figure 1. Location map of the target area

The main valley is generally flat with slope of 1:1000 between Ramlat As Sabatayn and Tarim and it is located at an altitude between 700 and 580 masl. It is boarded by the 200 to 300 m high cliffs (Northern and Sothern Jawl plateaus). The western part of the main valley is about 15 km wide, while east of Tarim it is only 1.5 km wide. The valley is covered by predominantly calcareous soils of low organic content. In some parts of the main valley highly saline soils occur.

The annual rainfall is less than 100 mm in the main valley and less than 50 mm and less than 50 mm on the Northern Jawl. Some parts of the Southern Jawls might receive from 100 to 300 mm/year. Large amount of annual precipitation may fall within few days during occasional rainstorm events.

Many tributaries of Wadi Hadhramawt dissect the bordering plateaus. The main southern tributaries include (from east to west): Wadi Doan, Wadi Al Ain, Wadi Bin Ali and Wadi Idim. The main northern tributaries are: Wadi Hinen, Wadi Madr, Wadi Thibi and Wadi Khun. During the wet seasons, the surface water is mostly available only in the upper and middle reaches of main tributaries, while the availability of flood water in the main valley is restricted only to periods with extremely heavy rains. In exceptional cases, the wadi channels are unable to accept the sudden arrival of heavy floods and the overflow washes away fertile topsoil and can cause the great destruction to life and property. The currently adopted mean annual runoff for Wadi Hadhramawt is estimated at 82 Mm^3/year [3]. More accurate estimates are not available at present.

The study area is confined to the large east-west oriented basin which is filled up with both marine and continental sediments. The Cretaceous formations - which consist of continental sandstone and shallow marine marl – outcrop in the escarpment of the main valley and its tributaries (Figure 2).

The Mukalla Formation (upper part of the Tawilah Group) consists of mostly friable sandstone with some interbedded mudstone, ironstone and shale. This formation is of regional extent and constitutes the most important aquifer in the study area. The Paleocene and Eocene formations (Jeza and Umm Er-Radhuma) consist of fractured carbonates and shales and form a regional cap to the plateaus.

Recent alluvium up to 100 m thick composed of clay, sand, gravel and silt covers the beds of the main valley and its tributaries. The Neogene conglomerates found in the subsurface of the main valley consists of hard limestone debris in a calcareous matrix that is variably fissured.

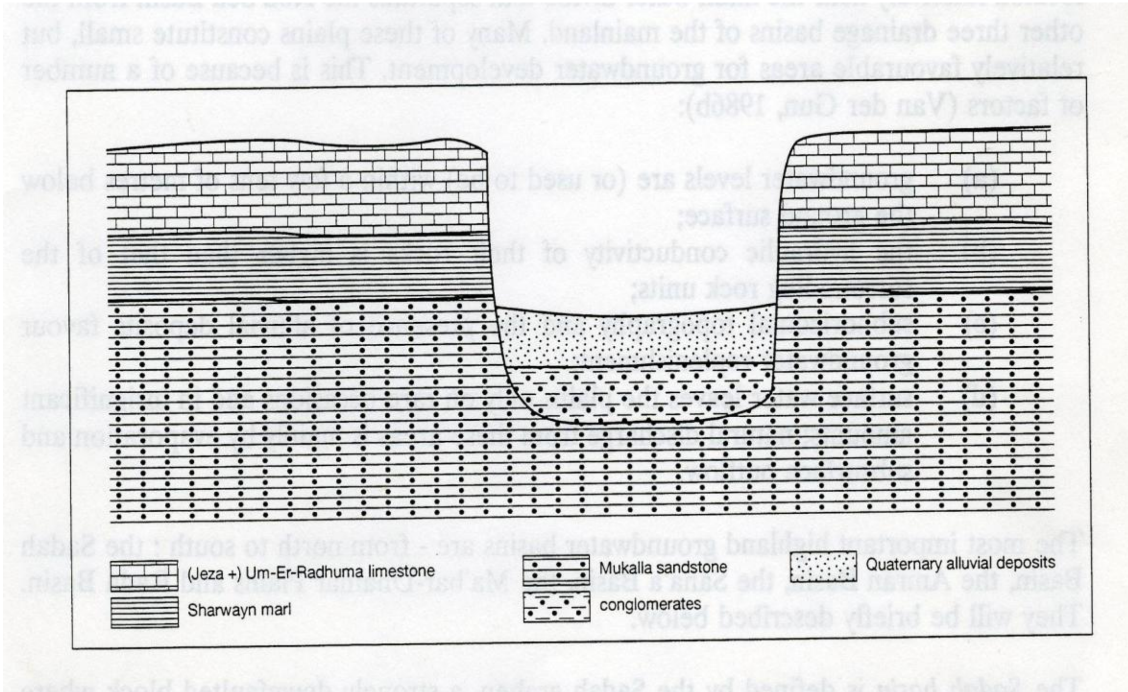

Figure 2. Schematic N-S geological cross-section

(Adopted from: [3])

3 GROUNDWATER OCCURRENCE

There are three main aquifers in Wadi Hadhramawt:

Quaternary alluvium: Recent sand and gravel deposits up to 100 m thick form the upper aquifer in the main valley and its tributaries. The maximum thickness is reported in the central part of Wadi Hadhramawt. Alluvium thins towards the valley sides and it is less developed in tributary wadis. Groundwater flow in the main valley follows the eastward downstream direction. The transmissivity values vary in wide range between tens and hundreds m^2/day [1].

Neogene conglomerates: This aquifer is composed of fractured and fissured calcareous conglomerates. Locally, evaporites are present that is important in terms of groundwater chemical composition. The conglomerate and the overlaying alluvium are hydraulically connected. The combined thickness of alluvium and conglomerate ranges between 10 – 200 m. Similar to the alluvium, the transmissivity values of conglomerates vary between tens and hundreds m^2/day [1].

Mukalla Sandstone: This aquifer is the most important groundwater source in Wadi Hadhramawt and is a part of the largest regional aquifer in the country. The sandstone from 120 to 500 m thick is fractured and, therefore, the groundwater can penetrate both the primary pores and the secondary fractures. Groundwater flow in this regional aquifer follows the dip of the formation from the west toward the north-east. The transmissivity values are reported to range between 300 – 1200 m^2/day [1].

Although the aquifer system in Wadi Hadhramawt is in general hydraulic continuity, it does not behave as a single unconfined aquifer, but rather as a stratified system comprising layers with distinct hydraulic properties. Depths to groundwater level range between 10 and 70 m [1].

On the Northern and Sothern Jawls, the Mukalla Sandstone aquifer is cover by shale, limestone and dolomite up to 250 m thick of the **Jeza and Umm Er-Radhuma Formations**. These formations have only secondary permeability due to fractures and/or karstification. On the elevated Jawl plateaus, the carbonate rock units contain only minor discontinuous aquifers and perched groundwater bodies but they play a crucial role in contributing recharge through downward percolation to the underlying sandstone.

4 BASIC HYDROCHEMISTRY (SYNTHESIS FROM OLD STUDIES)

A summary of conclusions from the older hydrochemical studies in Wadi Hadhramawt (Sogreah, 1981; Selkhozpromexport, 1983; Mott Macdonald, 1988; Goode Blizzard, 1996) can be found in the KOMEX's Draft Final report [1]. The general historic groundwater chemistry trends and interpretations include:

- Groundwater salinity has been reported by previous projects to increase towards the axis of the main valley and decrease towards the valley sides. The EC of groundwater in Wadi Hadhramawt Has been found to range between 590-13500 µS/cm.
- A general reduction in groundwater salinity was reported in the Mukalla aquifer immediately downstream of the confluence of large tributary wadis (Bin Ali, Idim) with the main valley. This phenomenon was assumed to be a result of a fresher groundwater inflow from the tributaries.
- The Mukalla sandstone groundwater has been reported as changing from a low salinity Ca-HCO_3 and Mg-HCO_3 water to Ca-SO_4 and Na-Cl rich water in the main valley with a general increase of salinity.

- In general, hydrochemistry of the Mukalla aquifer was reported to remain stable in time, while an increase of salinity was observed in groundwater contained in the shallow alluvium and conglomerate within the main valley.

- It was concluded by the previous water projects that the elevated groundwater salinity found along the axis of the main valley was a result of dissolution of evaporites which were deposited in the alluvium and conglomerate. Additional source of elevated salinity was attributed due to irrigation return flows.

5 HYDROCHEMICAL ENVIRONMENT IN 2001 (MAJOR OUTPUTS OF THE KOMEX STUDY)

Based on the data collected by KOMEX [1], the major ion chemistry is evaluated taking into account a total of 91 water samples collected in 2001from the wells which were repeatedly sampled by NWRA in 2011. Three main groundwater hydrochemical types have been identified in Wadi Hadhramawt based on Piper analysis of groundwater samples as shown in Figure 3.

1. Ca/Mg-HCO_3 type which reflects the dissolution of limestone and/or dolomite by carbon dioxide enriched rain and surface water.

2. Na/K-SO_4/Cl type that is associated with the recharge from surface flows along the main wadi through mainly saline and somewhere polluted soil.

3. Indiscriminate ions type which represents mixing of type 1 with more saline water in the main wadi channel.

The distribution of different types of groundwater within the target area is shown in Figure 4.

Each of the hydrochemical types was found in each of the three main aquifers available in Wadi Hadhramawt. This phenomenon reflects the different contributions of recharge from different sources (both natural and man-made) and the evolution of groundwater composition within different rock units.

The main difference in the groundwater composition between the three aquifers can be illustrated in the terms of the total salinity expressed as the total dissolved solids (TDS) content.

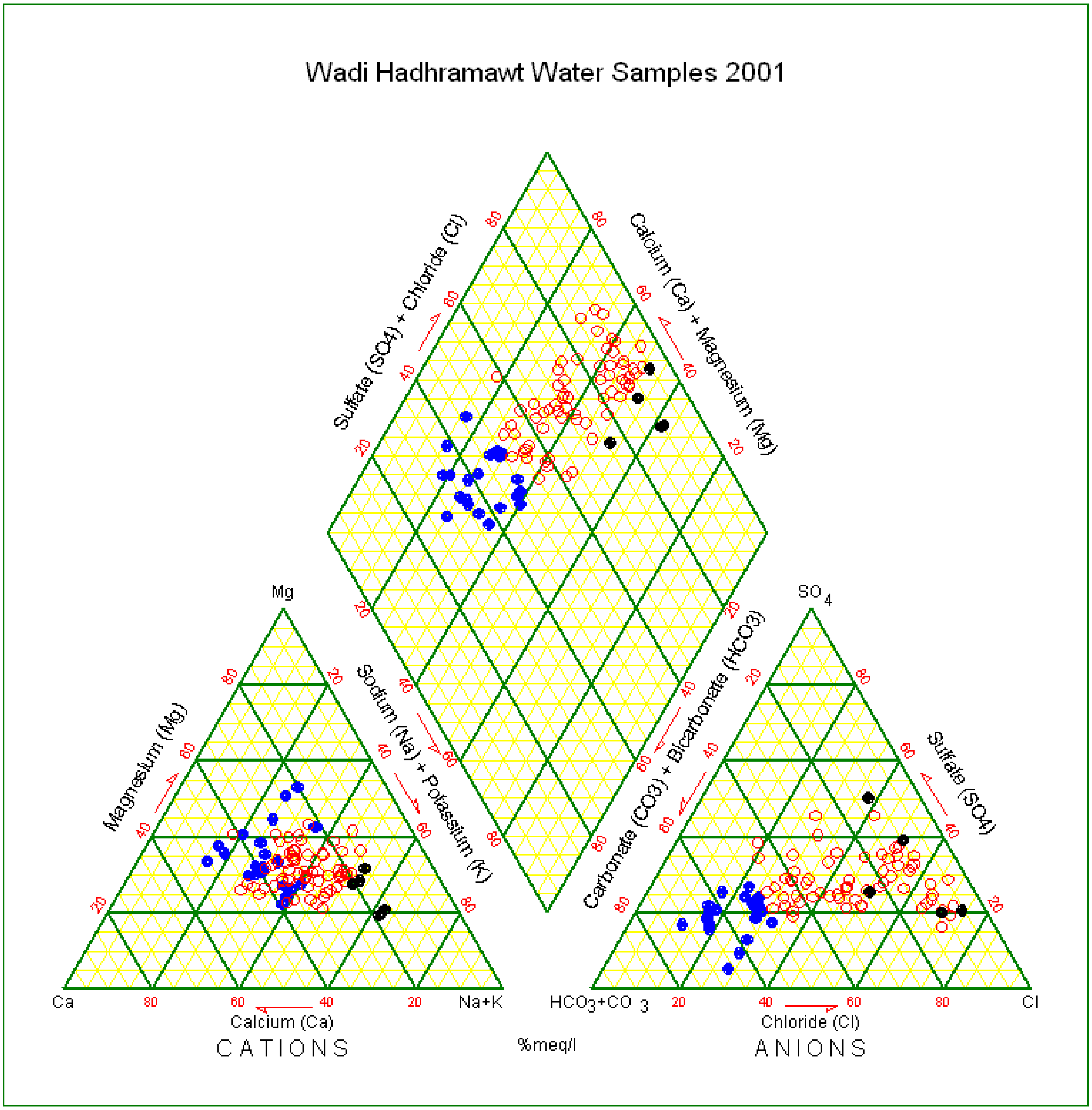

Figure 3. Piper diagram of groundwater samples collected in 2001

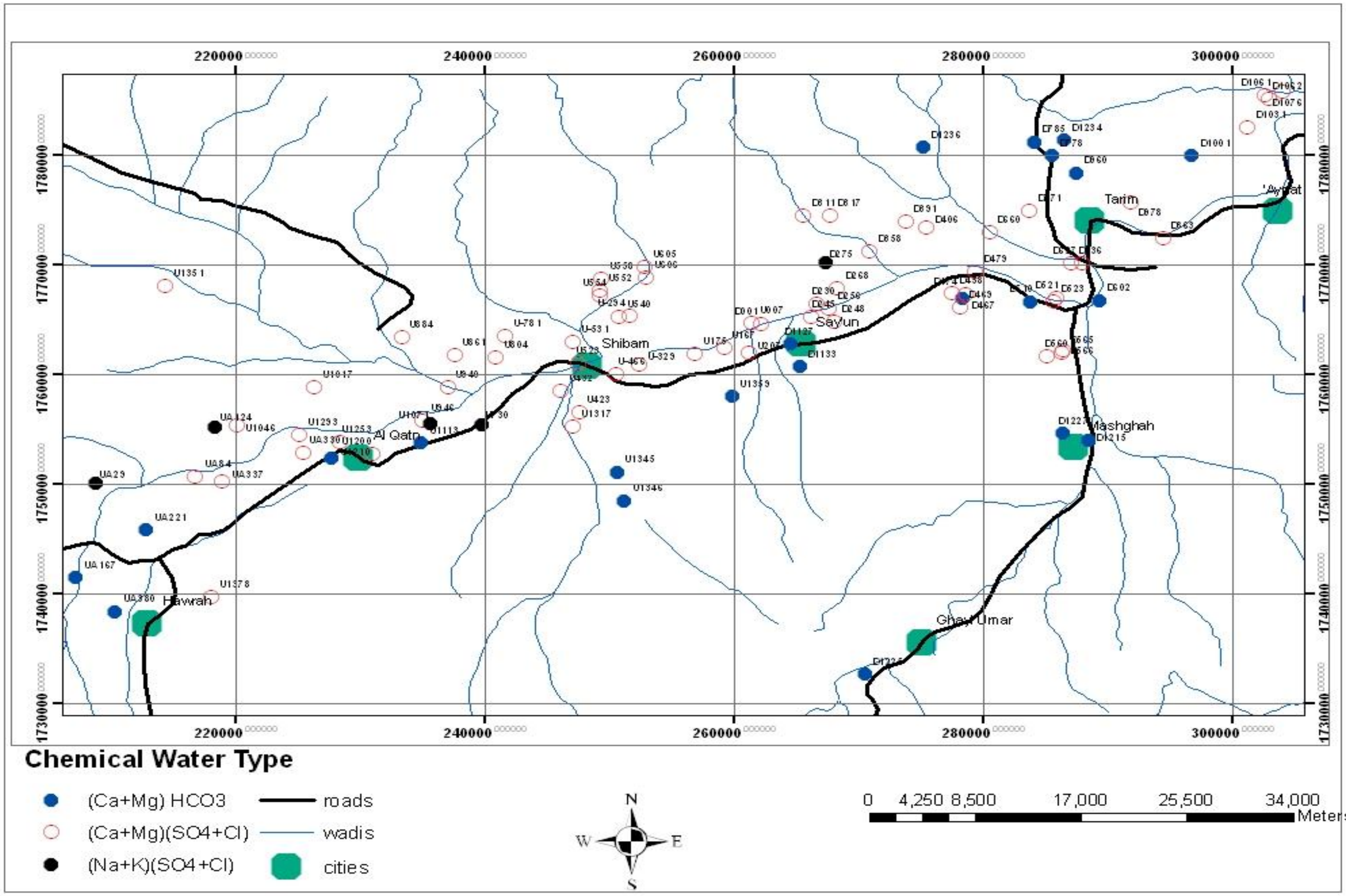

Figure 4. Distribution of hydrochemical types of groundwater in 2001

Alluvium. Groundwater in the alluvium has been characterized by the TDS values ranging between 413-9430 mg/l. Only 15% of water analyses showed TDC concentrations lower than 1000 mg/l. The highest TDS concentrations have been found in the central part of the main valley. The highest salinity zone extended from Shibam eastwards to the confluence of the main wadi with Wadi Tarb, and further east from Tarim to Qasam. There was also a small area of higher salinity close to Al Qatn. The groundwater was observed to be fresher along the margins of the main valley.

Conglomerate. The TDS concentrations ranged between 655-7026 mg/l with 20% of the samples showed concentrations lower than 1000 mg/l. The distribution pattern of salinity in the conglomerate was reported to be similar to that in the alluvium.

Mukalla Sandstone. Groundwater from the sandstone showed TDS concentrations between 433 and 4550 mg/l. The majority of samples (80%) showed TDC concentrations lower than 1000 mg/l. Fresh groundwater was found in the boreholes located in the tributary wadis and at the margins of the main valley. In the central part of the main valley the salinity was found to be slighter higher. The highest salinity values were found between Al Qatn and Shibam and to the west of Seyun.

The following principal sources of salinity in Wadi Hadhramawt have been defined by KOMEX [1]:

- Salt accumulation in the main valley due to evaporation of infiltrating surface water;
- Salt domes and outcrops of evaporates in Ramlat As Sabatayn desert located upstream of the main valley;
- Occurrence of evaporites which were deposited during formation of the conglomerate;
- Pollution from agricultural and domestic sources.

The spatial distribution of the important mineral constituents which seem to be the principal indicators of salinity and potential groundwater pollution (EC, Cl, Na and NO_3) is shown in Figures 5 – 8 based on the outputs of the KOMEX's hydrochemical study [1].

A summary of the original analyses of water samples collected by KOMEX is appended to this report in **Annex 1**.

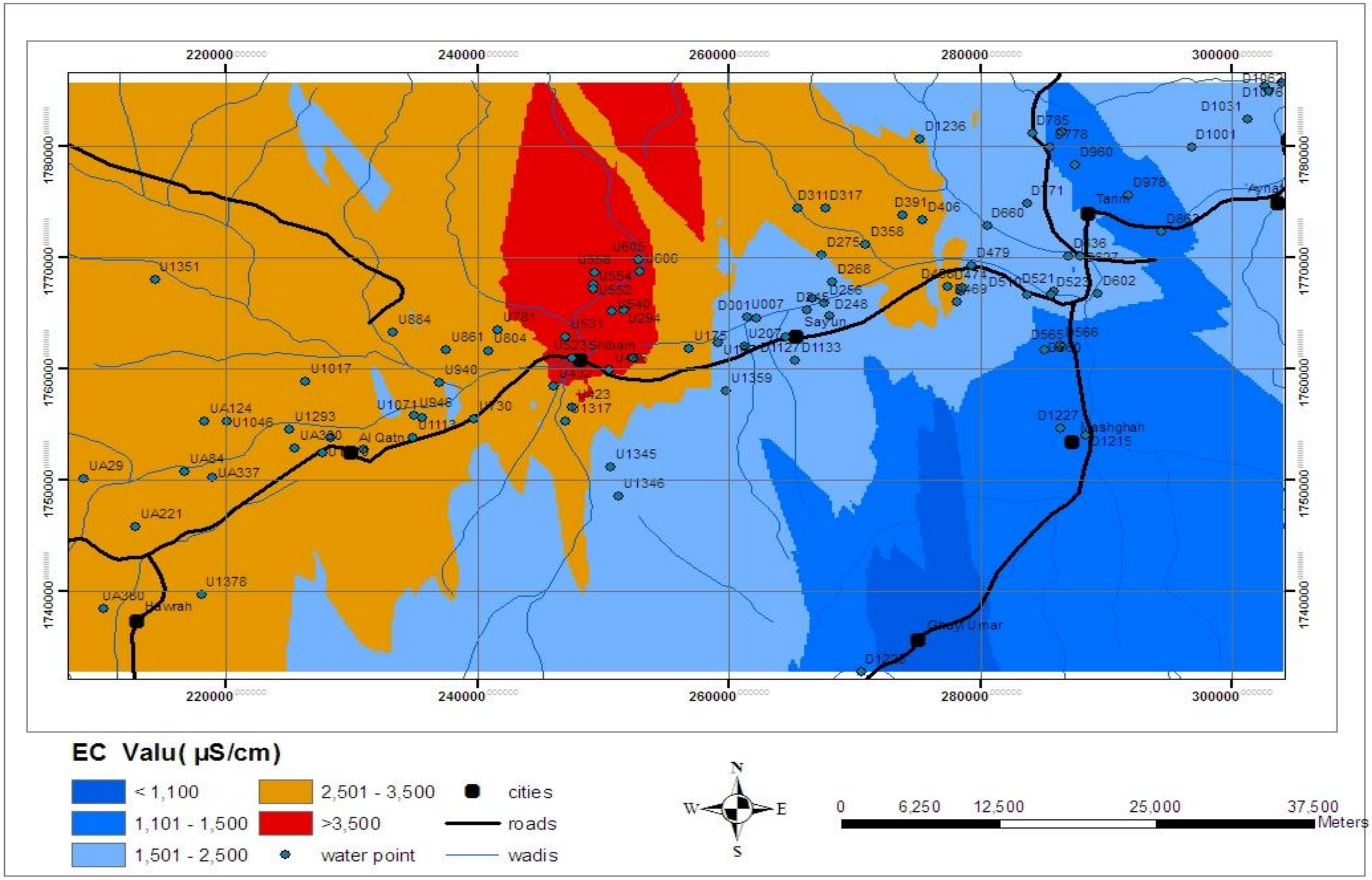

Figure 5. EC distribution in groundwater (2001)

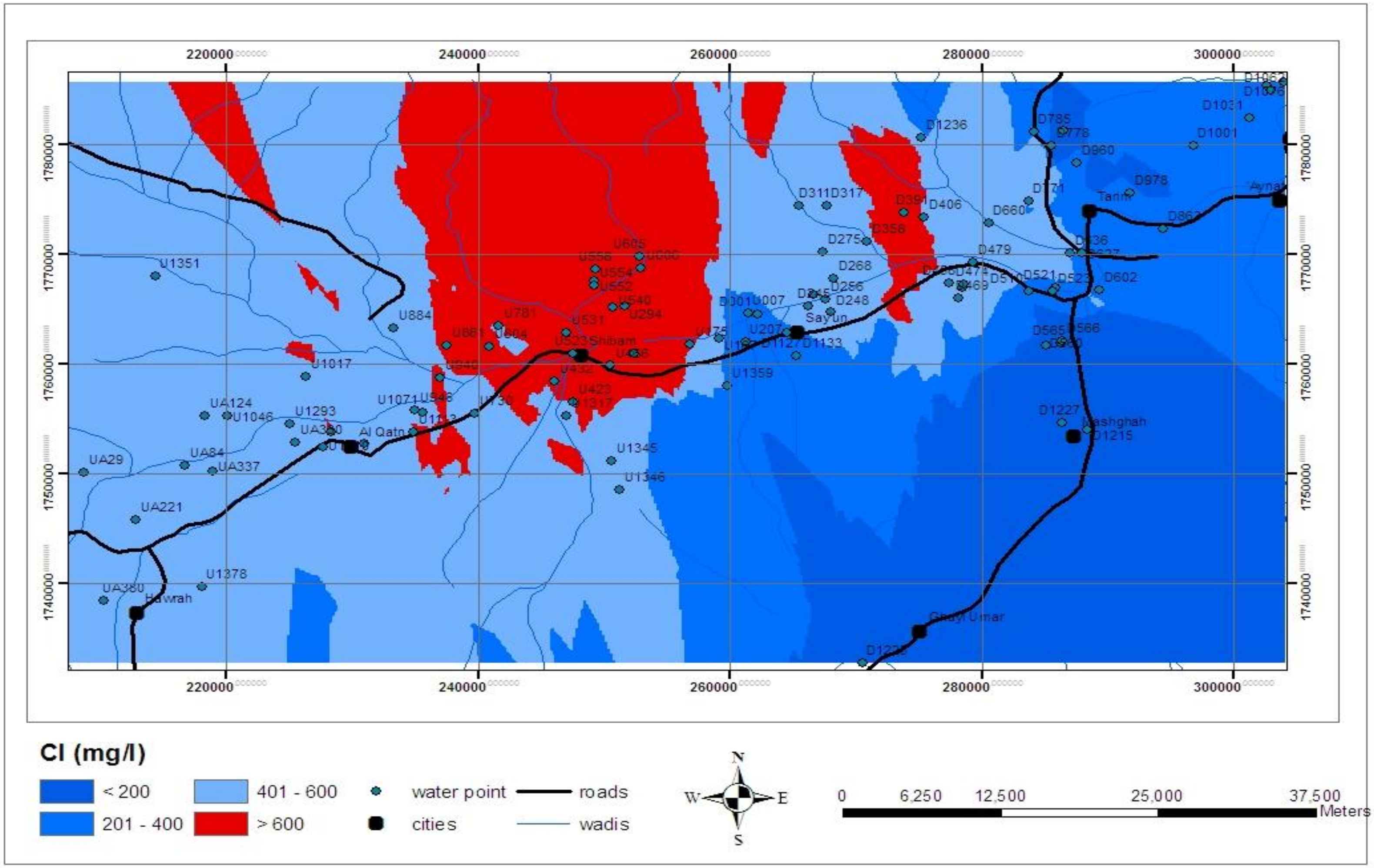

Figure 6. Chloride distribution in groundwater (2001)

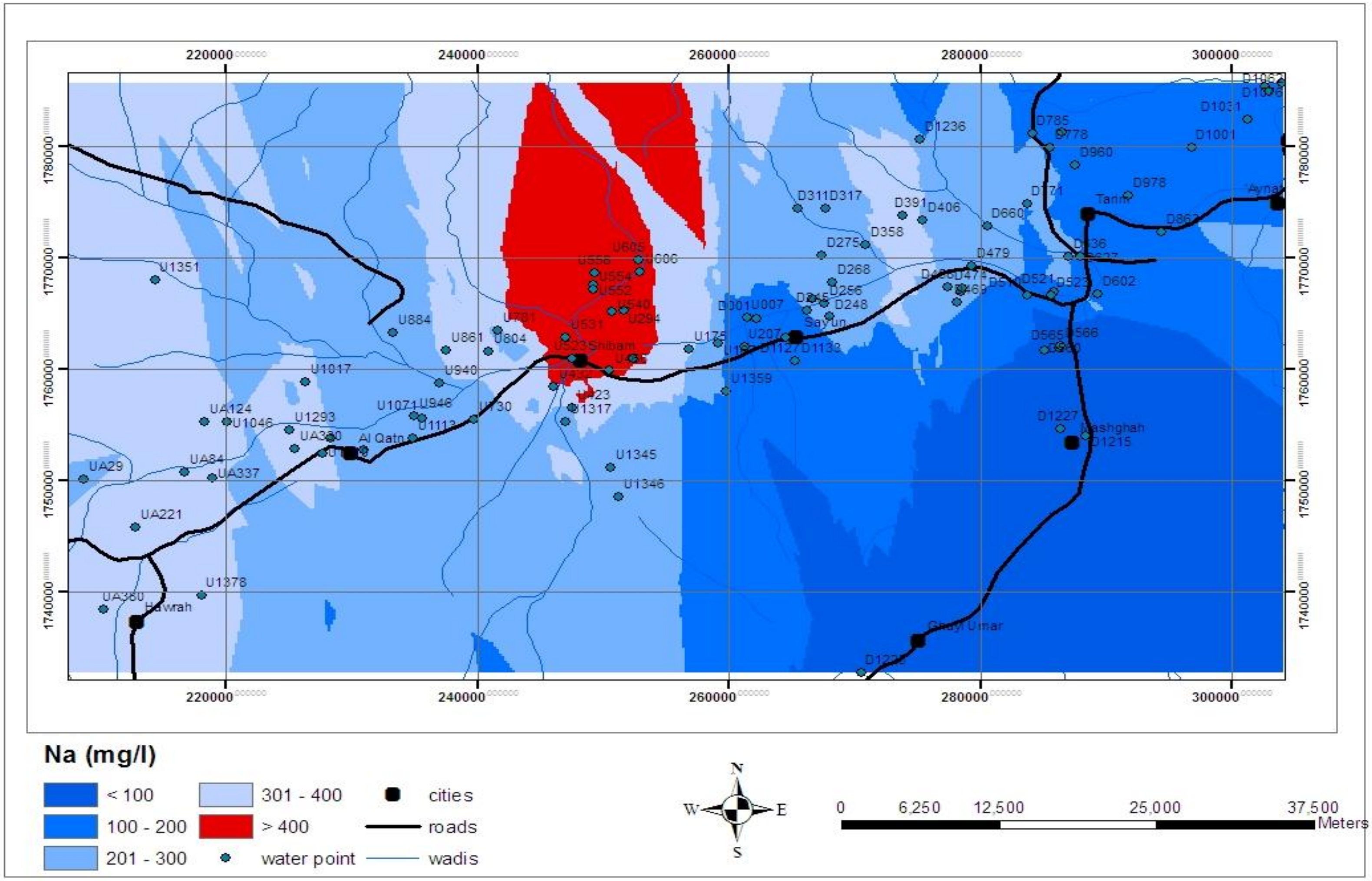

Figure 7. Sodium distribution in groundwater (2001)

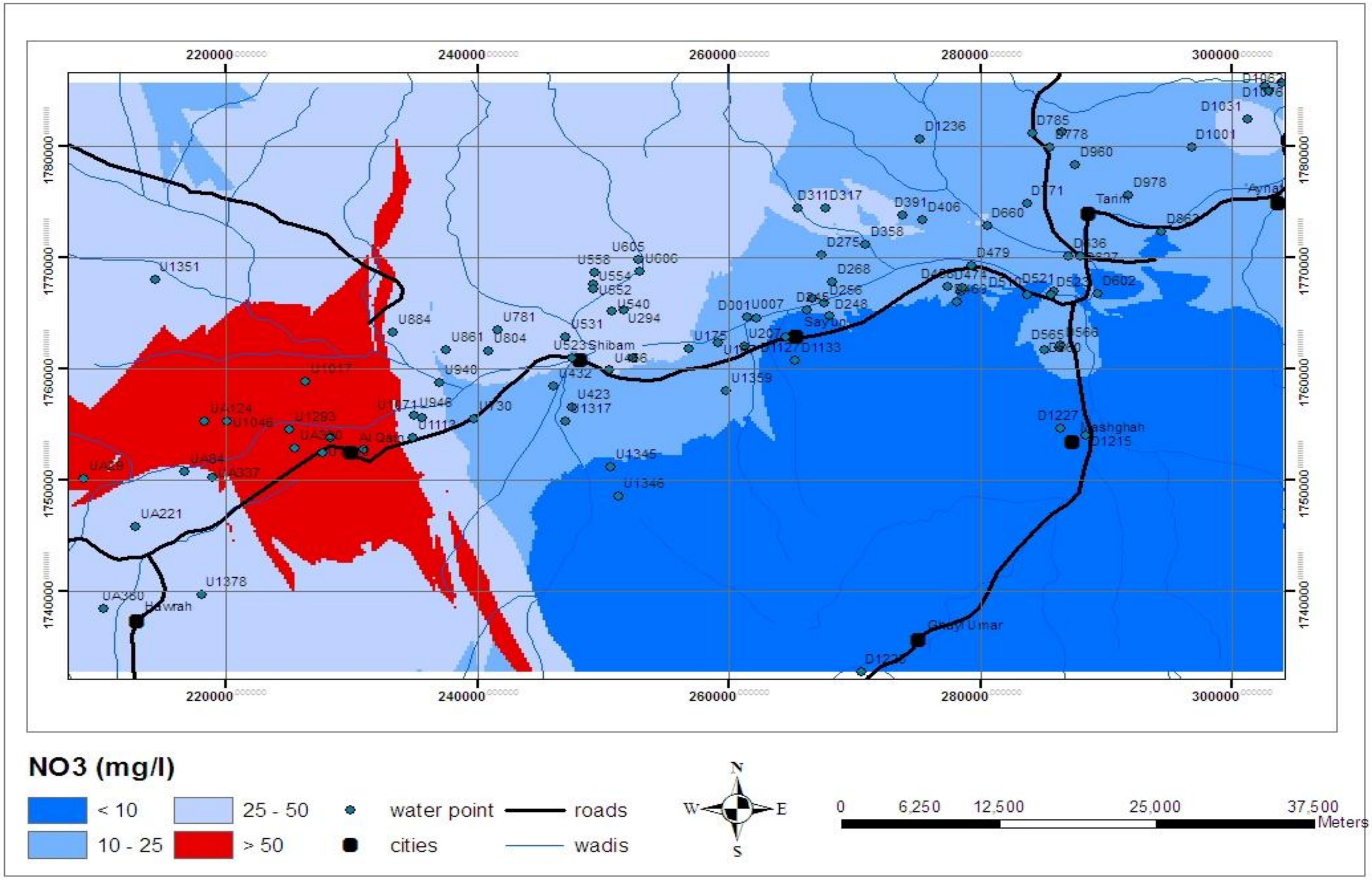

Figure 8. Nitrate distribution in groundwater (2001)

It was concluded by KOMEX [1] that the chloride concentration is the main indicator of salinity in groundwater from all three aquifers.

Temporal variations in groundwater composition might have natural causes, but usually they are related to human activities. By comparing chemical analyses from 1986 and 2001, respectively, KOMEX [1] has evaluated temporal changes in TDS. It was found that groundwater salinity has generally remained stable over fifteen years. This indicates that irrigation return flows or other pollution sources did not influence the recharged water. There was evidence in salinity increase in the central part of the main valley, especially in those parts where urbanized area dramatically expended (Ghusays, Hadiyah, Al Qatn and Al Ghuraf). The public (NWSA) wells located at Seyun and Tarim showed stable groundwater salinity, probably due to proper design of operating boreholes which prevented contamination from shallower aquifers.

6 HYDROCHEMICAL ENVIRONMENT IN 2011

6.1 Sampling and analysis program

In April-May, 2011, a total of 123 water samples have been collected by the Seyun Branch Office of NWRA (Field Team: Helmi Abd Hamdan and Abdulaziz S. Ba-Musleh) under the NPWRM Program from the wells located in different parts of the main valley of Wadi Hadhramawt and its tributaries. Sampling point locations are shown in Figure 9. Coordinates of sampling points and characteristics of sampled wells can be found in **Annex 2**.

Well and aquifer performance data collected by the NWRA/Seyun field team from the sampled water points are summarized in **Annex 3**.

Analysis of collected water samples for major ions has been carried out in the chemical laboratory at the Seyun Branch of NWRA. The methods used to determine chemical constituents are listed in Table 1.

The quality of chemical analyses was checked by the ion balance based on calculations of meq/l. The results are considered satisfactory because the errors in the calculated ionic balances are less than 5% for all water samples.

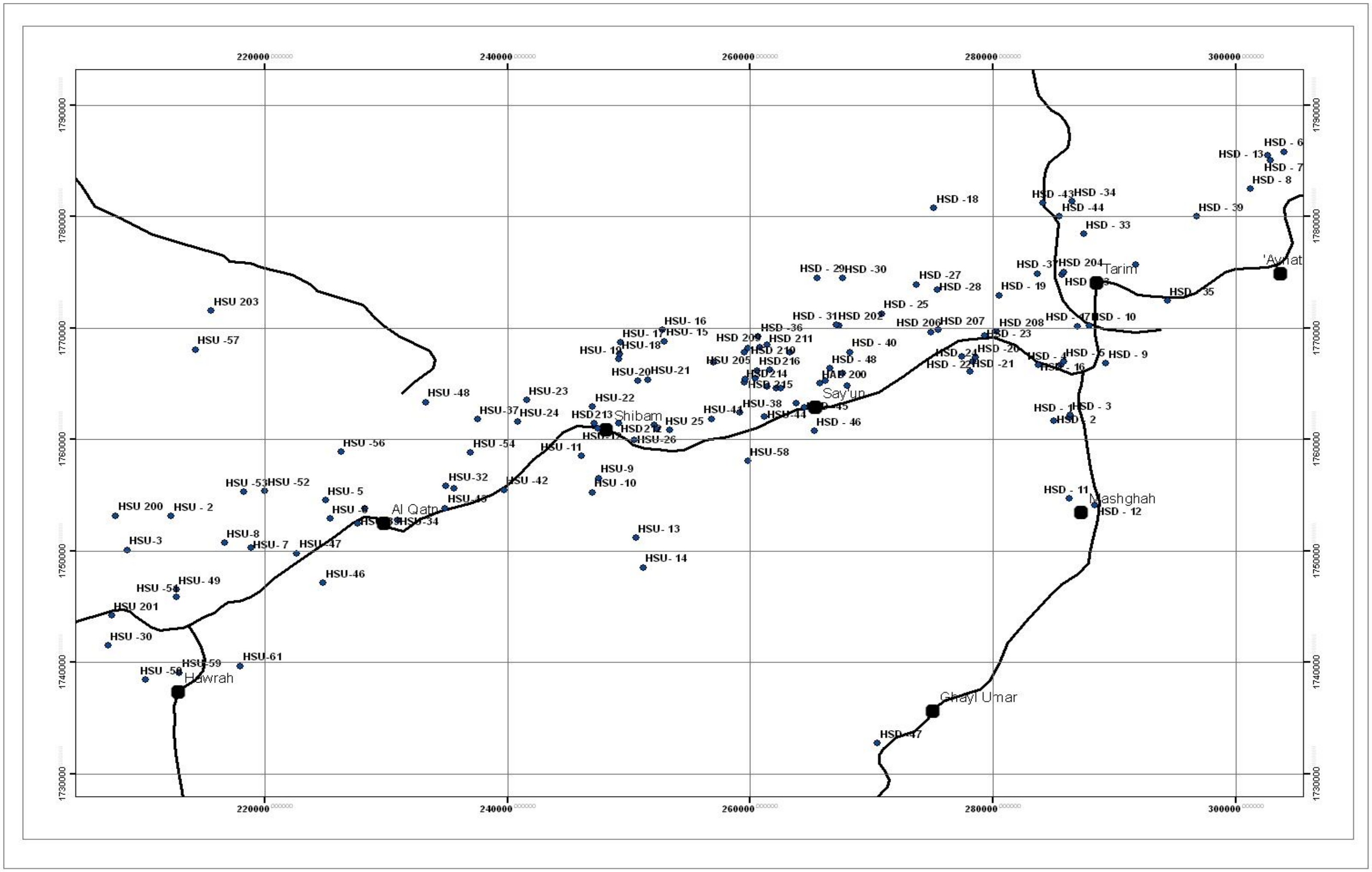

Figure 9. Sampling point locations (2011)

Table 1. Methods used to determine chemical parameters

Parameter	Method
Total Alkalinity	Titration with acid
Bicarbonate	
Carbonate	
Total Hardness, Calcium	EDTA Titration method
Magnesium	Calculated from Calcium and Hardness results
Sodium	Flame photometry (JENWAY)
Potassium	
Chloride	Titration with $AgNO_3$ or $Hg(NO_3)_2$
Sulfate	SulfaVer 4 with Barium
Nitrate	Spectrophotometer (DR 2800 HACH)
Florida	Spectrophotometer (DR 2800 HACH)
Iron	Spectrophotometer (DR 2800 HACH)

6.2 Summary of collected data

A summary of the original analyses of water samples collected by the NWRA/Seyun field team in 2011 under the present NPIWRM study and chemically analyzed by the Seyun Branch Office of NWRA is appended to this report in **Annex 4**.

Based on the data collected by the NWRA/Seyun field team, the major ion chemistry is evaluated taking into account a total of 91 water samples collected in 2011from the wells which were previously sampled by KOMEX in 2001. The three main groundwater hydrochemical types similar to those previously identified by KOMEX have been identified in Wadi Hadhramawt based on Piper analysis of groundwater samples as shown in Figure 10.

The distribution of different types of groundwater within the target area is shown in Figure 11.

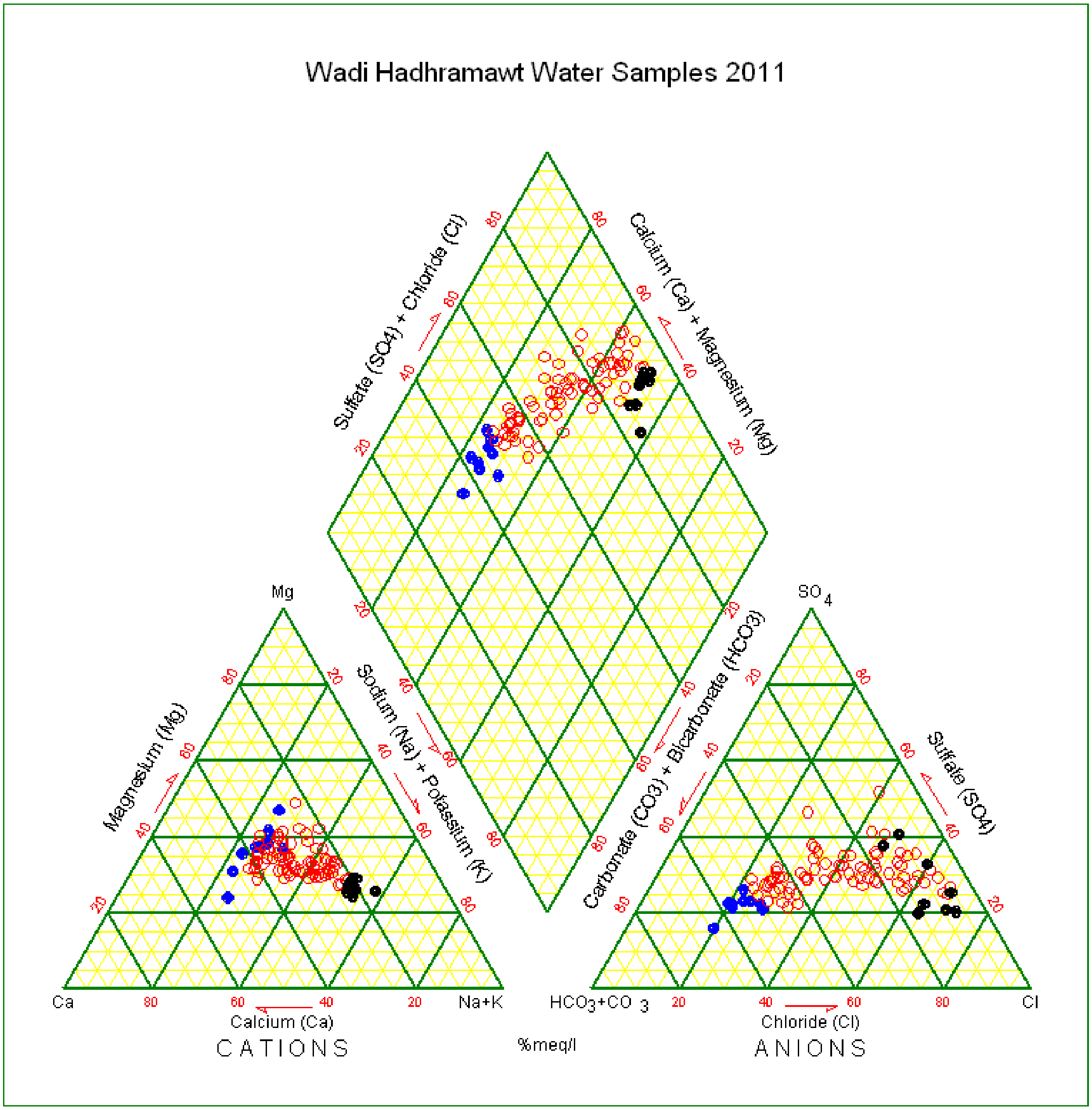

Figure 10. Piper diagram of groundwater samples collected in 2011

1. **Ca/Mg-HCO$_3$ type** (shown as blue circles in Figure 11) reflects the dissolution of limestone and/or dolomite by carbon dioxide enriched rain and surface water. This groundwater is mostly reported in the southern tributary wadis and is characterized by domination of HCO_3 anion which is an indicator of recharge associated with carbonate rock units within the plateau and contributing fresh groundwater from southern tributaries to the main valley.

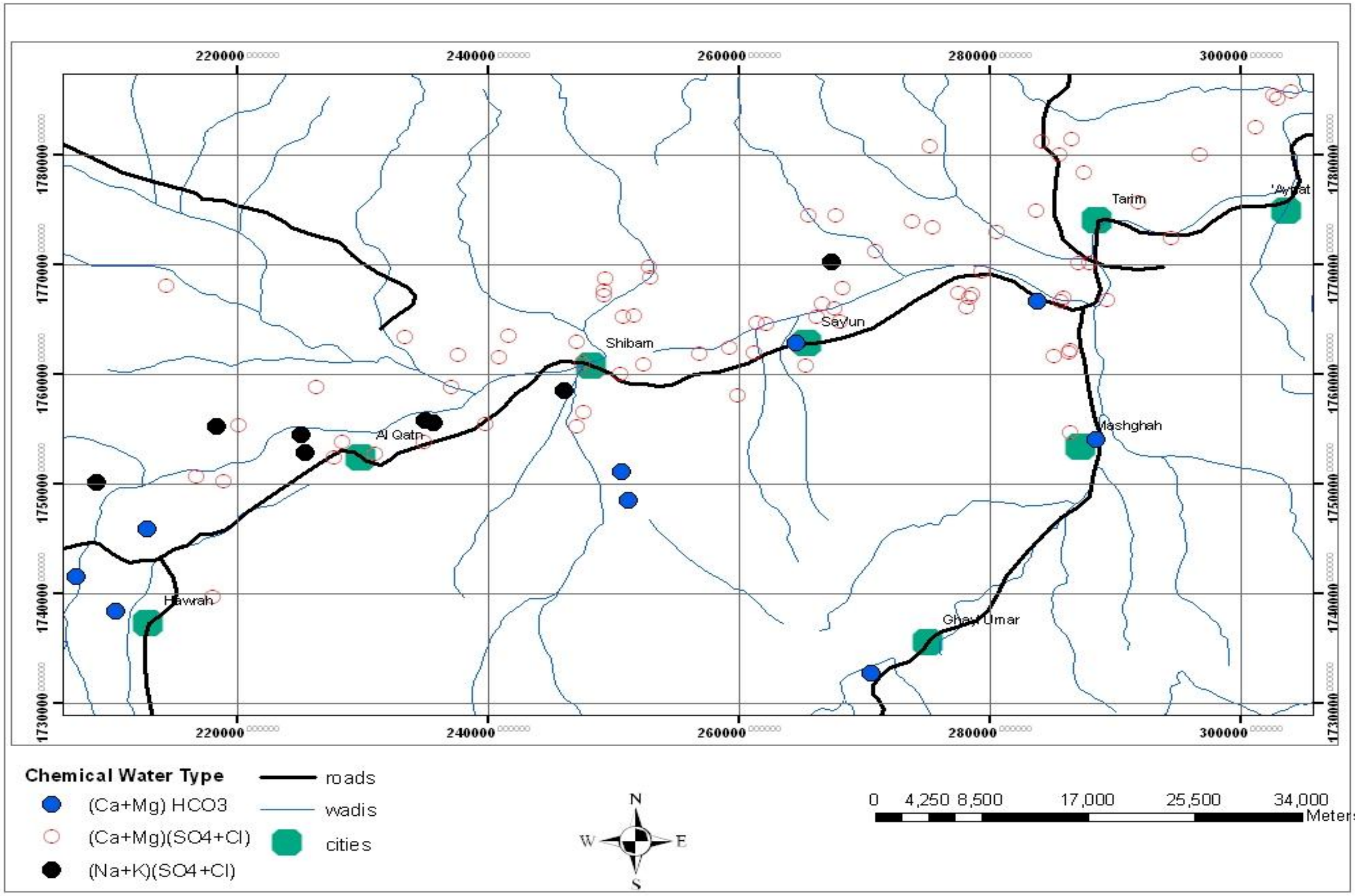

Figure 11. Distribution of hydrochemical types of groundwater in 2011

2. **Na/K-SO_4/Cl type** of groundwater (shown as black circles in Figure 11) is reported to occur along the axis of the main valley. This type is associated with the recharge from surface flows through mainly saline and somewhere polluted soil. The elevated concentrations of sodium and potassium might also be associated with dissolution of salt domes outcropping in the Ramlat As Sabatayn desert located to the west (upstream) of Wadi Hadhramawt.

3. **Indiscriminate ions type** of groundwater (shown as violet circles in Figure 11) is characterized by elevated proportions of chloride and sulfate that may indicate a hydrochemical evolution of Type 1 water due to reduction of HCO_3 and enrichment of other anions as groundwater passes through a source of Cl and SO_4. The occurrence of this water type within the northern plateau may be associated with the lithology of the Paleocene and Eocene formations (Jeza and Umm Er-Radhuma) which may include halite, gypsum and anhydrite. In the main valley, this water type seems to be associated with mixing of Type 1 recently recharged groundwater with more saline water in the main wadi channel.

The spatial distribution of the important mineral constituents which seem to be the principal indicators of salinity and potential groundwater pollution (EC, Cl, Na and NO_3) is shown in Figures 12 – 15 based on the outputs of the NWRA's hydrochemical study in Wadi Hadhramawt [2].

7 HYDROCHEMICAL EVOLUTION BETWEEN 2001 AND 2011

The results of the recent NWRA hydrochemical study summarized in the present report, is compared against some of the data collected by KOMEX more than a decade ago in order to evaluate temporal changes in groundwater salinity and chemical composition in different parts of Wadi Hadhramawt.

As discussed in Section 6.2, the three main groundwater hydrochemical types have been identified by NWRA in 2011. These types are similar to those previously identified by KOMEX in 2001.

A comparison summary of hydrochemical water types is shown in Table 2. This summary includes a total of 91 water samples collected from the same wells in 2001 and 2011, respectively.

Table 2. Summary of chemical water types in 2001 and 2011

Year	Chemical Groundwater Type						Total	
	$(Ca+Mg)(SO_4+Cl)$ Type 3		$(Ca+Mg)(HCO_3)$ Type 1		$(Na+K)(SO_4+Cl)$ Type 2			
	Number of samples	%	Number of samples	%	Number of samples	%	Number of samples	%
2001	64	70.3	22	24.2	5	5.5	91	100
2011	74	81.3	9	9.9	8	8.8	91	100

It is clear from Table 2 that the most significant change in the general hydrochemical environment between 2001 and 2011 is that the percentage of Ca/Mg-HCO_3 type of groundwater (Type 1) has been radically reduced in 2011 as compared with the same wells sampled in 2001 (from 24% to 10% only). As shown in Figures 4 and 11, the evolution of HCO_3-rich water to Ca/Mg-SO_4/Cl water (Type 3) is reported from many wells situated in the main valley (six wells), several northern tributaries (six wells) and even in the southern tributary Wadi Idim which contribute a significant proportion of the fresh groundwater recharge to the main valley (one well located close to the town of Mashgrah). This negative environmental trend very probably links to increasing land development (both urban and agricultural) and associated pollution.

Other changes in hydrochemical types between 2001 and 2011 are not so significant (see Table 2). These evolutions from Type 2 to Type 3 and vice versa reflect the continuous mixing between different water types in the main valley and show changes in different contributions of recharge from different sources.

The two sets of thematic hydrochemical maps showing the spatial distribution of the important mineral constituents which seem to be the principal indicators of salinity and potential groundwater pollution (EC, Cl, Na and NO_3) have been constructed based on outputs of 2001 KOMEX and 2011 NWRA studies, respectively (Figures 5-8 and 12-15). The pairs of appropriate thematic maps provide a basis for some evaluation of changes in salinity and some principal groundwater constituents over the last decade in different parts of Wadi Hadhramawt.

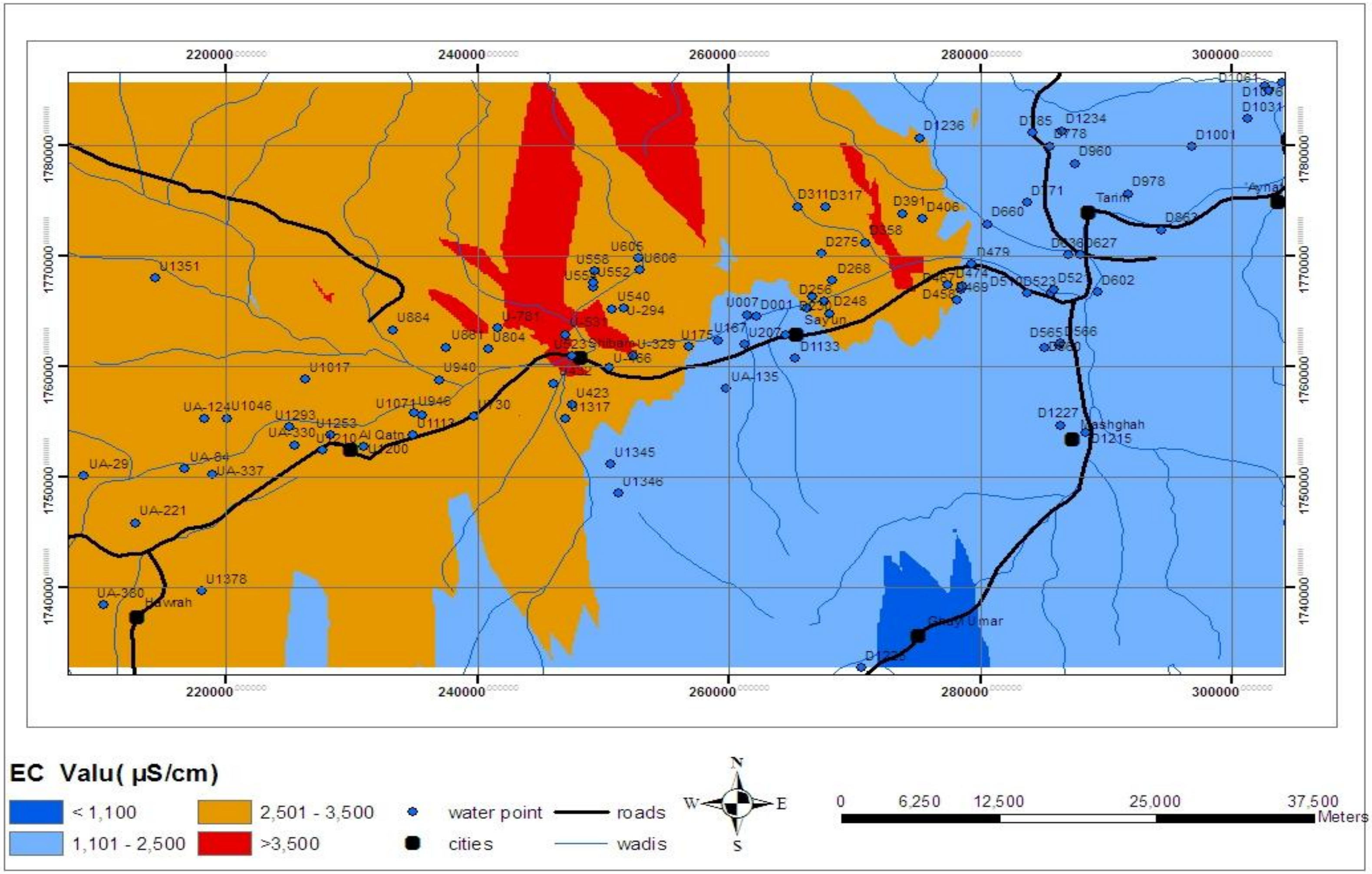

Figure 12. EC distribution in groundwater (2011)

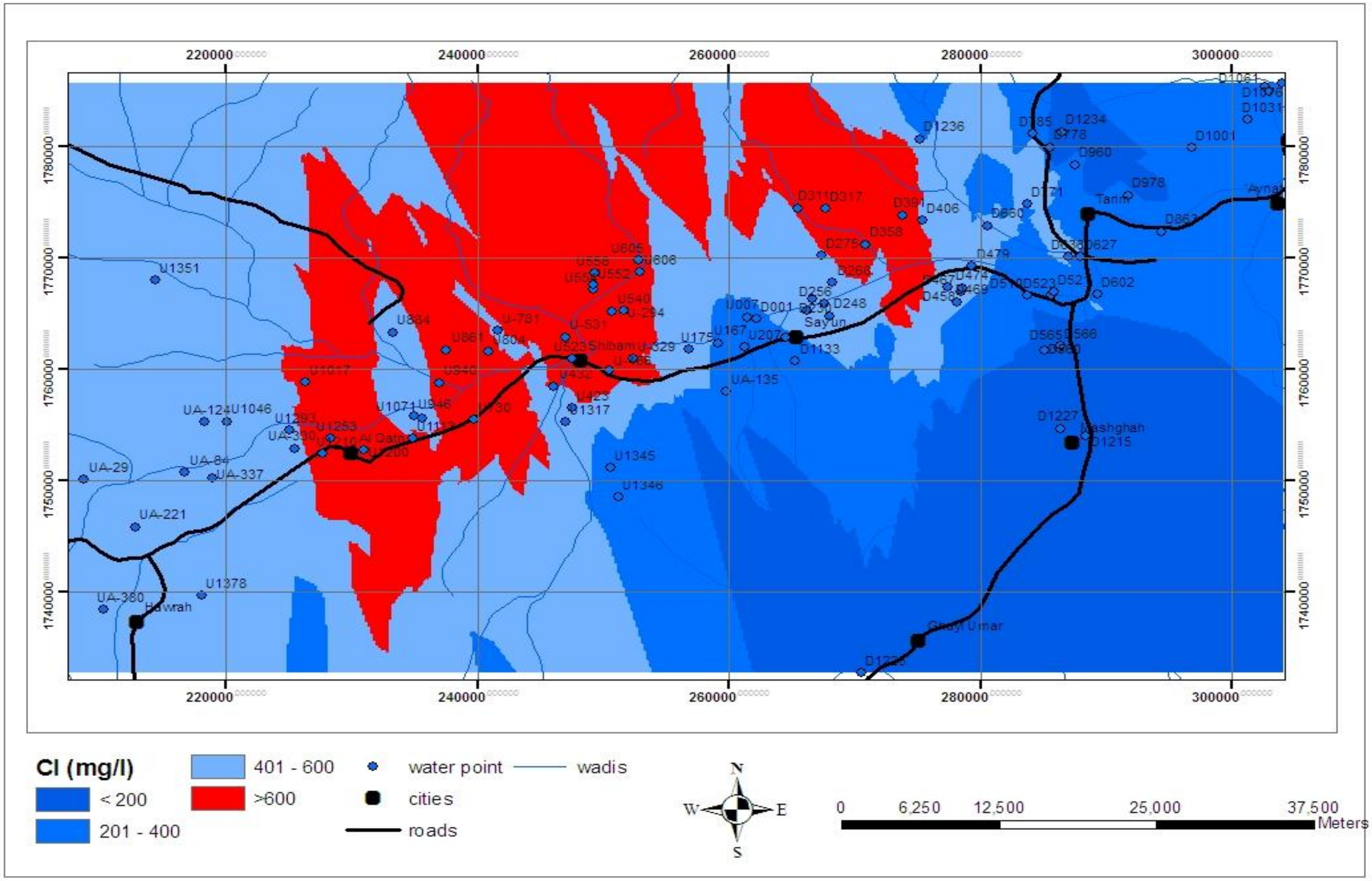

Figure 13. Chloride distribution in groundwater (2011)

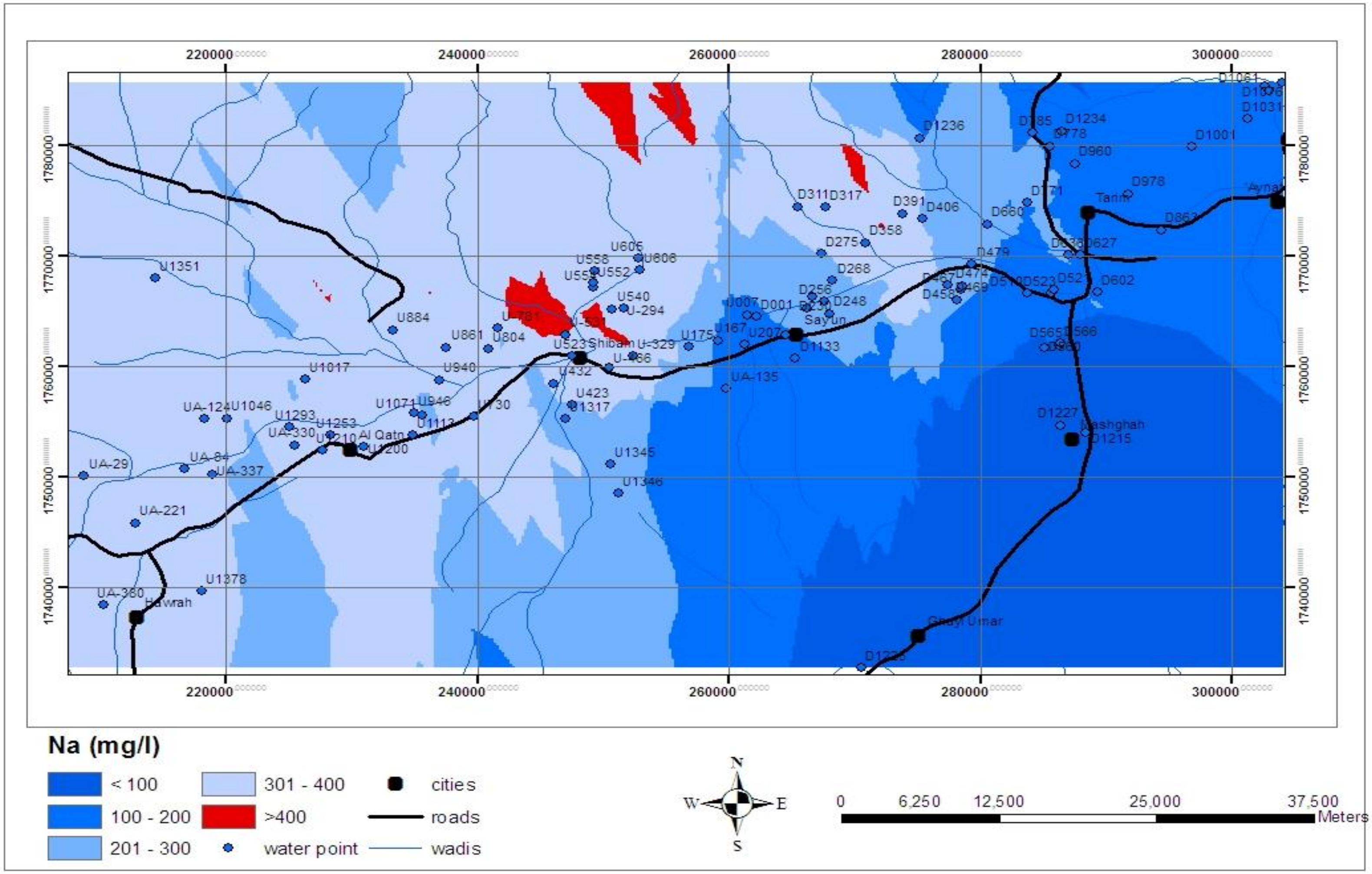

Figure 14. Sodium distribution in groundwater (2011)

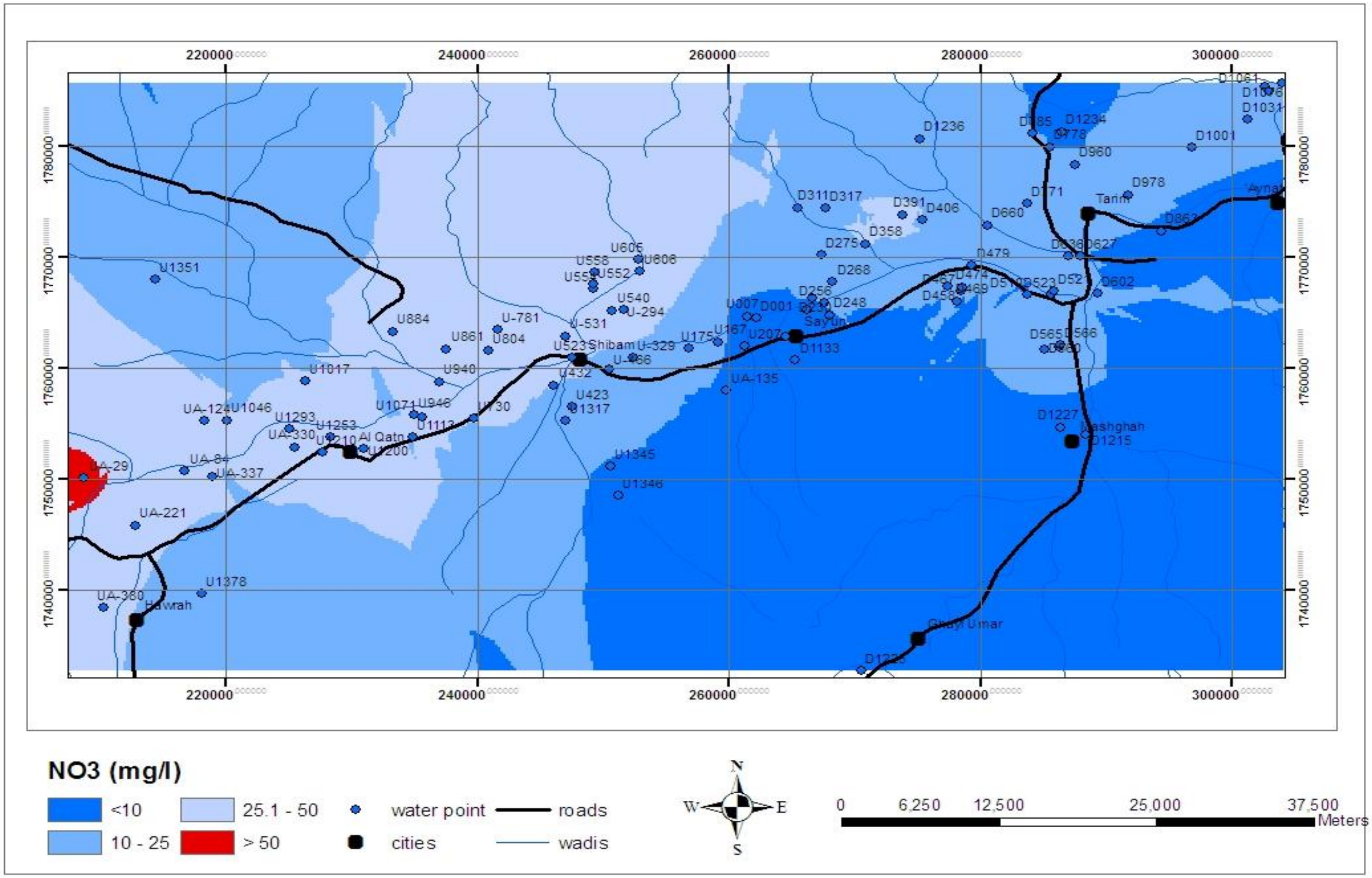

Figure 15. Nitrate distribution in groundwater (2011)

It is evident from the comparison between Figures 5 and 12 that no significant changes in groundwater salinity patterns is reported between 2001 and 2011 except for an expansion of the elevated salinity areas located in the southern tributary wadis. This trend might be associated with urban and/or agricultural land development during the last decade. The expansion of elevated salinity water did not link, however, with a general increase of chloride- and sodium-rich waters in these areas as evident from the comparison between the pairs of relevant thematic maps (Figures 6 and 13; 7 and 14).

A lack of a general increase of chloride- and sodium-rich waters in the southern tributary wadis reflects continuation of groundwater recharge along these tributaries while irrigation return flows or other pollution sources did not significantly influence the recharged water. The general pattern of low salinity groundwater is modified when enters the main valley by mixing of different water types and probably by pollution in urban and agricultural lands.

There is some evidence of a decrease in salinity at the outlet of the main valley east of Tarim (Figures 5 and 12) that might be explained by an increase of fresh groundwater recharge contributing to the main valley from Wadi Idim, especially due to the heavy flood event reported in 2008.

The generally low salinity groundwater is modified when enters from the tributaries to the main valley by mixing with more saline water and probably by pollution in urban and agricultural lands. On the other hand, however, there is some evidence of significant reduction in the nitrate concentration between 2001 and 2011 in the area west of Al Qatn (Figures 8 and 15) that likely reflects improving land development.

The composition of infiltrating rain and surface water is modified as it comes into the contact with soil crusts and aquifer sediments. Variations in groundwater composition might have natural causes, but usually they are related to different human activities. In particular, due to high abstraction from the sandstone aquifer in Wadi Hadhramawt over the last decades, the vertical gradient of groundwater flow reversed locally. As a result, the brackish, saline or polluted groundwater from the shallower aquifers (alluvium and conglomerate) might mix with the originally fresh water stored in the sandstone.

A summary of compared chemical data available for different aquifers from the 2001 KOMEX study [1] and the 2011 NWRA set of analyses [2] is presented in **Annexes 5, 6 and 7**. The first name of the well in each sample ID pair refers to the unique name provided by KOMEX, followed by the original name provided to the same well by the NWRA field team. The important note is that only those water samples which are definitely related to individual aquifers under abstraction are selected for the following comparison analysis.

7.1 Alluvial aquifer

The chemical analyses of water samples collected by KOMEX from 6 wells are compared against the NWRA analysis results as tabulated in **Annex 5**.

Figure 16 shows the variations in TDS concentrations between 2001 and 2011 for six wells tapped the alluvial aquifer in different parts of the target area. Evidence derived from Figure 16 suggests that:

- The low TDS concentration found in the downstream part of tributary wadi Bin Ali (HSU-9) has decreased over the last decade that reflects an increase of fresh groundwater recharge along this southern tributary. An analysis of the long term groundwater-level monitoring records is required to support this hypothesis.

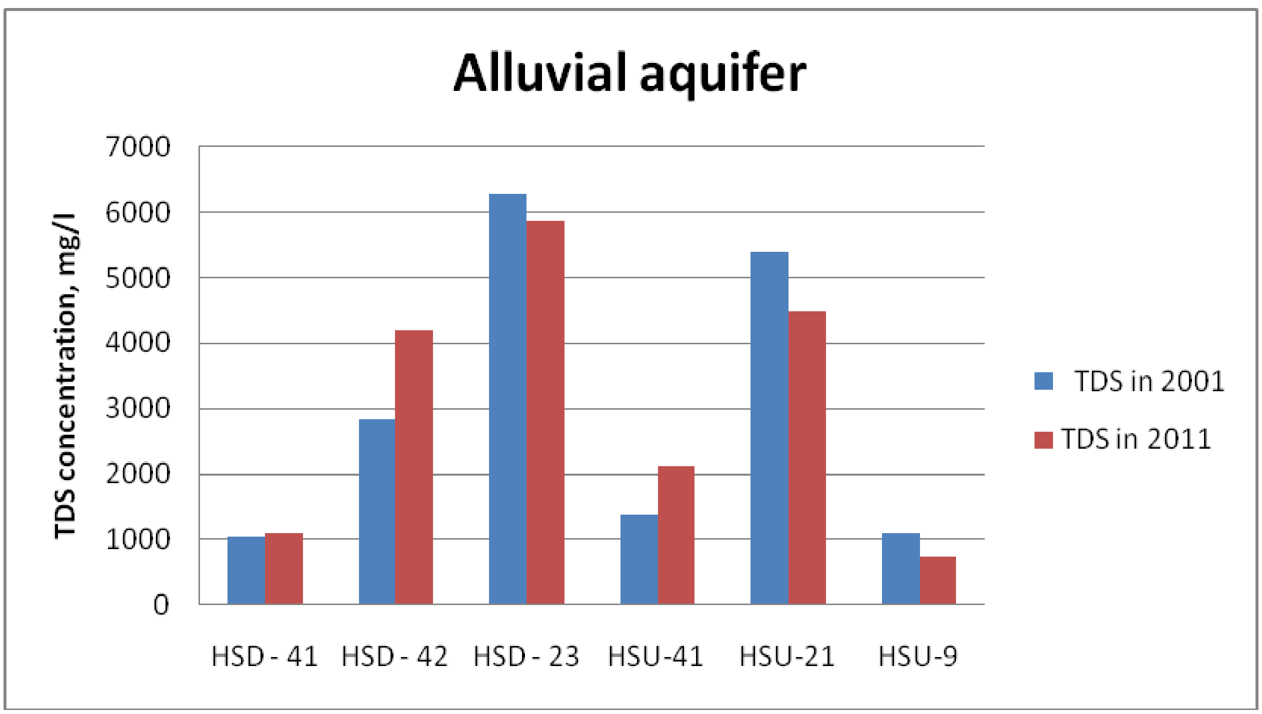

Figure 16. Alluvial aquifer: Variations in TDS concentrations between 2001 and 2011

- A decrease in generally elevated TDS concentrations between 2001 and 2011 is also reported from two wells located in the central (HSU-21) and eastern (HSD-23) parts of the main valley that reflects rather stable land development at these locations. At one sampling point (HSD-41), the groundwater salinity remained nearly stable that indicates a lack of significant pollution sources at these locations.

- An increase in groundwater salinity between 2001 and 2011 is reported from two wells located in the central (HSU-41) and eastern parts of the main valley that reflects a possible influence of groundwater pollution.

7.2 Conglomerate aquifer

The chemical analyses of water samples collected by KOMEX from 17 wells are compared against the NWRA analysis results as tabulated in **Annex 6**. Three pairs of water samples (HSD-13/D-1061, HSU-27/U-326 and HSU-53/UA-124) have been excluded from a comparison because of enormous differences between 2001 and 2011 data which are difficult to explain.

Figure 17 shows the variations in TDS concentrations between 2001 and 2011 for seventeen wells tapped the conglomerate aquifer in different parts of the target area. Evidence derived from Figure 25 suggests that:

- An increase in groundwater salinity between 2001 and 2011 is reported from six wells that reflects a possible influence of groundwater pollution. Four wells are located in the eastern (HSD-22, HSD-10) and central (HSU-11, HSU-24) parts of the main valley. Two wells are located in the downstream parts of the northern tributary wadis: Wadi Madr (HSD-29) and Wadi Khun (HSD-7), respectively.

- At four sampling points located in the central (HSU-12 and HSU-19) and eastern (HSD-15) parts of the main valley, and also in the middle part of the southern tributary Wadi Idim (HSD-11), the groundwater salinity remained nearly stable. This indicates a lack of significant pollution sources at these locations.

- A decrease in groundwater salinity between 2001 and 2011 is reported from seven wells located in the northern tributary Wadi Madr (HSD-30) and also in the eastern (HSD-21, HSD-32), central (HSU-20, HSU-18, HSU-15) and western (HSU-6) parts of the main valley. This pattern of change might reflect an increase of fresh groundwater recharge. An analysis of the long term groundwater-level monitoring records is required to support this hypothesis.

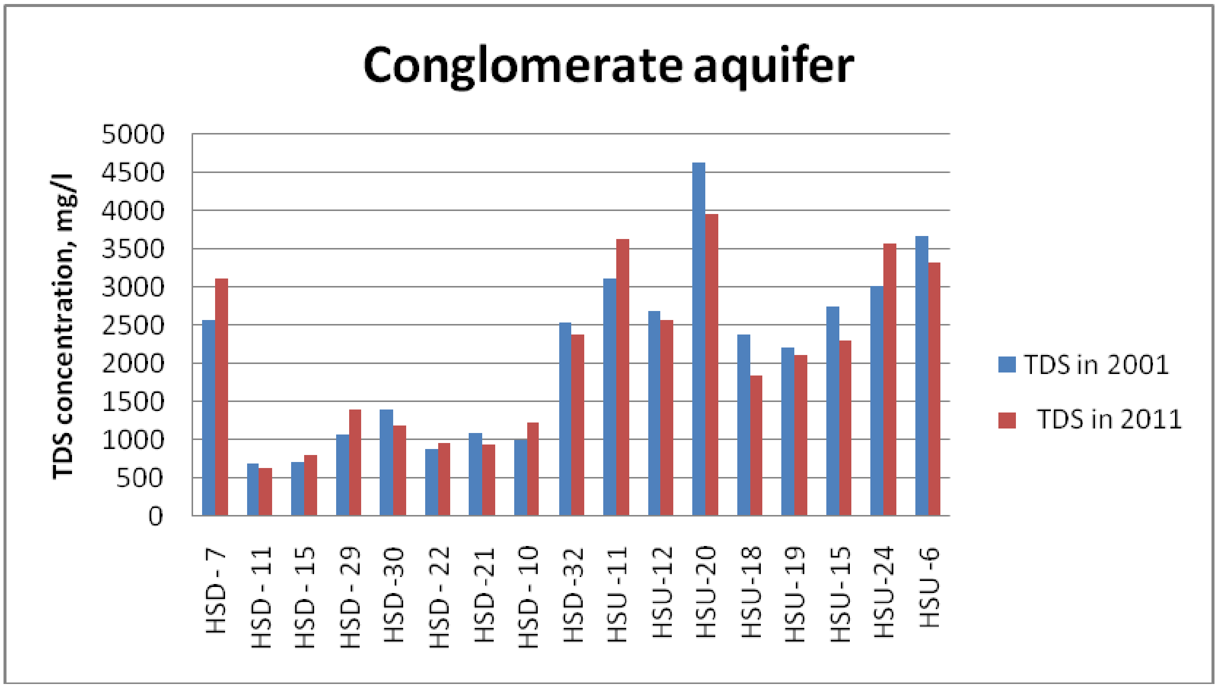

Figure 17. Conglomerate aquifer: Variations in TDS concentrations between 2001 and 2011

7.3 Sandstone aquifer

The chemical analyses of water samples collected by KOMEX from 53 wells are compared against the NWRA analysis results as tabulated in **Annex 7**.

Figures 18-22 show the variations in TDS concentrations between 2001 and 2011 for fifty-three wells tapped the sandstone aquifer in different parts of the target area.

In the **western part of the main valley** (approximately west of Shibam), the two different patterns of a change in groundwater salinity between 2001 and 2011 might be distinguished as shown in Figure 18.

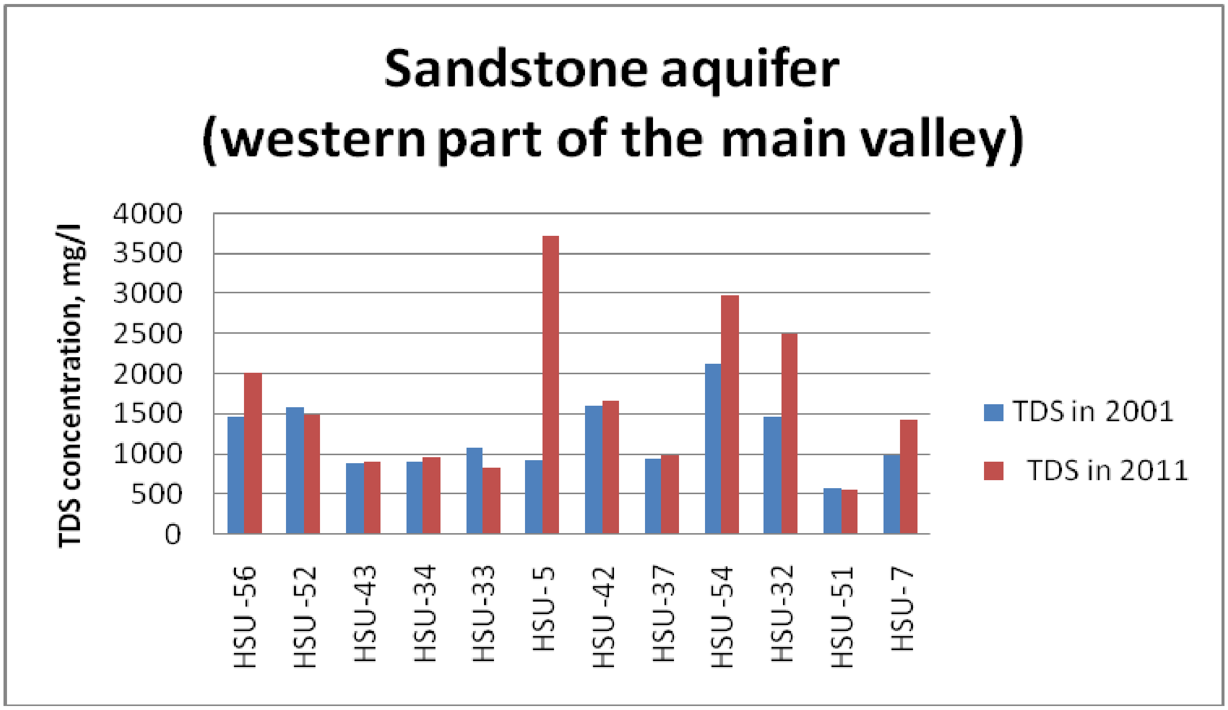

Figure 18. Sandstone aquifer (western part of the main valley): Variations in TDS concentrations between 2001 and 2011

These patterns include:

1) Nearly stable or slightly decreasing groundwater salinity between 2001 and 2011 is reported from seven wells (HSU-52, HSU-43, HSU-34, HSU-33, HSU-42, HSU-37 and HSU-51). This indicates that originally fresh groundwater stored in the sandstone is not modified in these locations by mixing with more saline or polluted water from the shallower aquifers (alluvium and conglomerate).

2) Increase in groundwater salinity is reported from five wells (HSU-56, HSU-5, HSU-54, HSU-32 and HSU-7). This indicates a possible influence of groundwater from the shallower aquifers in conditions when the vertical gradient of groundwater flow is reversed due to high abstraction from the sandstone aquifer.

In the **central part of the main valley** (approximately between Shibam and Seyun), nearly stable (slightly increasing or slightly decreasing) groundwater salinity is reported from five wells (HSU-38, HSU-44, HSU-26, HSU-22 and HSU-17) as shown in Figure 19.

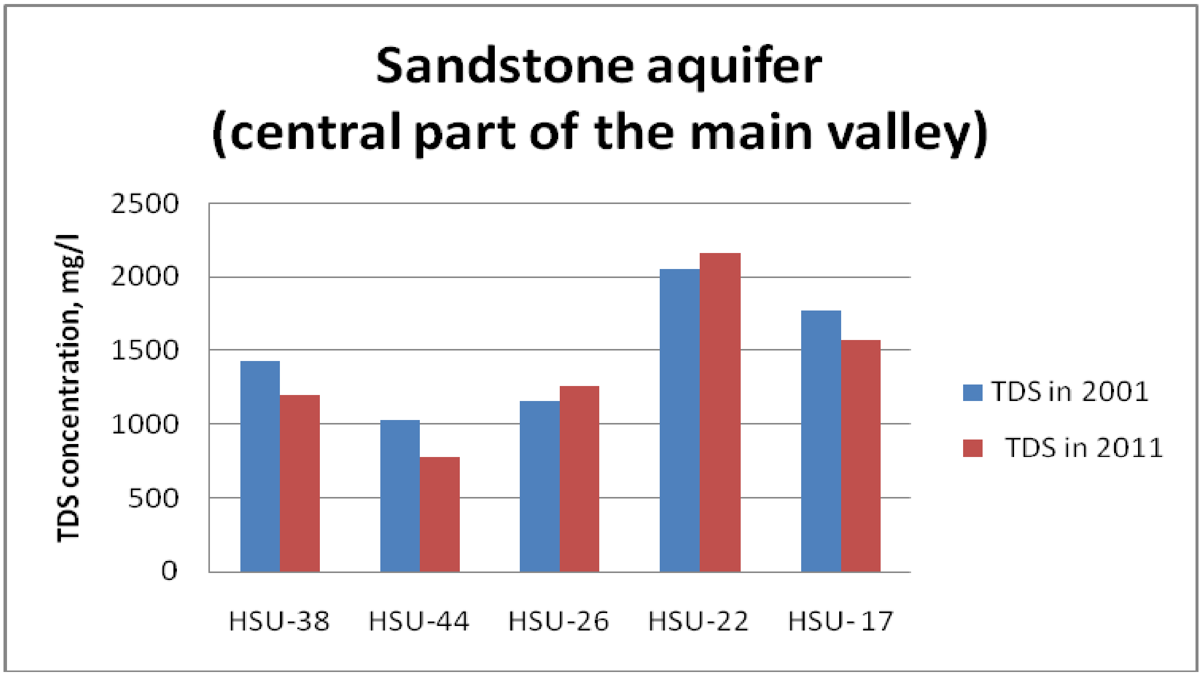

Figure 19. Sandstone aquifer (central part of the main valley): Variations in TDS concentrations between 2001 and 2011

This pattern of a lack of significant temporal change in groundwater salinity between 2001 and 2011 indicates a lack of significant pollution sources at these locations.

In the **eastern part of the main valley** (approximately east of Seyun) the two different patterns of a change in groundwater salinity between 2001 and 2011 might be distinguished as shown in Figure 20.

These patterns include;

1) Nearly stable (or slightly decreasing/increasing) groundwater salinity between 2001 and 2011 is reported from eighteen wells (HSD-45, HSD-46, HSD-48, HSD-38, HSD-25, HSD-27, HSD-28, HSD-24, HSD-20, HSD-16, HSD-5, HSD-4, HSD-9, HSD-17, HSD-19, HSD-37, HSU-31 and HSD-35). This predominant pattern indicates that originally fresh groundwater stored in the sandstone is not modified in these locations by mixing with more saline or polluted water from the shallower aquifers (alluvium and conglomerate).

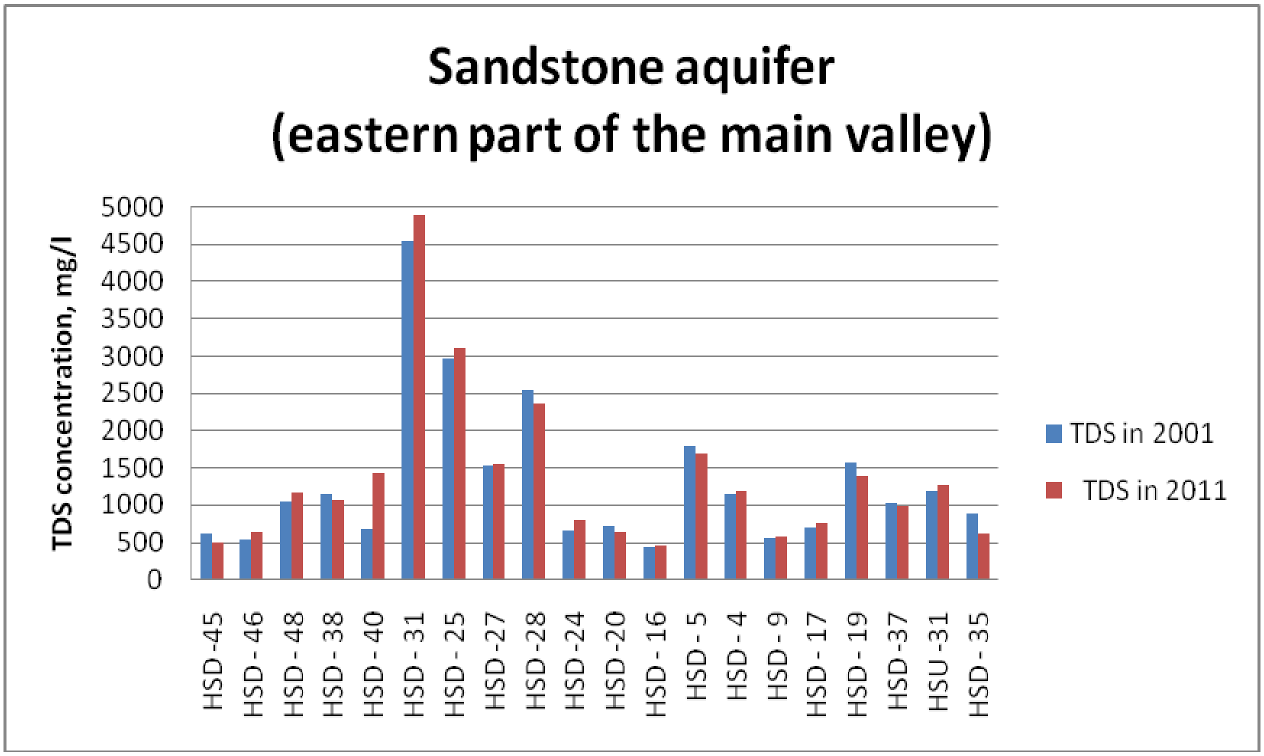

Figure 20. Sandstone aquifer (eastern part of the main valley): Variations in TDS concentrations between 2001 and 2011

2) Increase in groundwater salinity is reported from only two wells (HSD-40 and HSD-31). This indicates a possible influence of groundwater from the shallower aquifers in conditions when the vertical gradient of groundwater flow is reversed due to high abstraction from the sandstone aquifer.

All seven water samples collected in the **northern tributary wadis** (HSD-44, HSD-43, HSD-33, HSU-16, HSD-39, HSD-8 and HSD-6) show nearly stable (or slightly decreasing/increasing) groundwater salinity between 2001 and 2011 as shown in Figure 21.

This pattern indicates that originally fresh groundwater stored in the sandstone is not modified in the northern tributary wadis by mixing with more saline or polluted water from the shallower aquifers (alluvium and conglomerate).

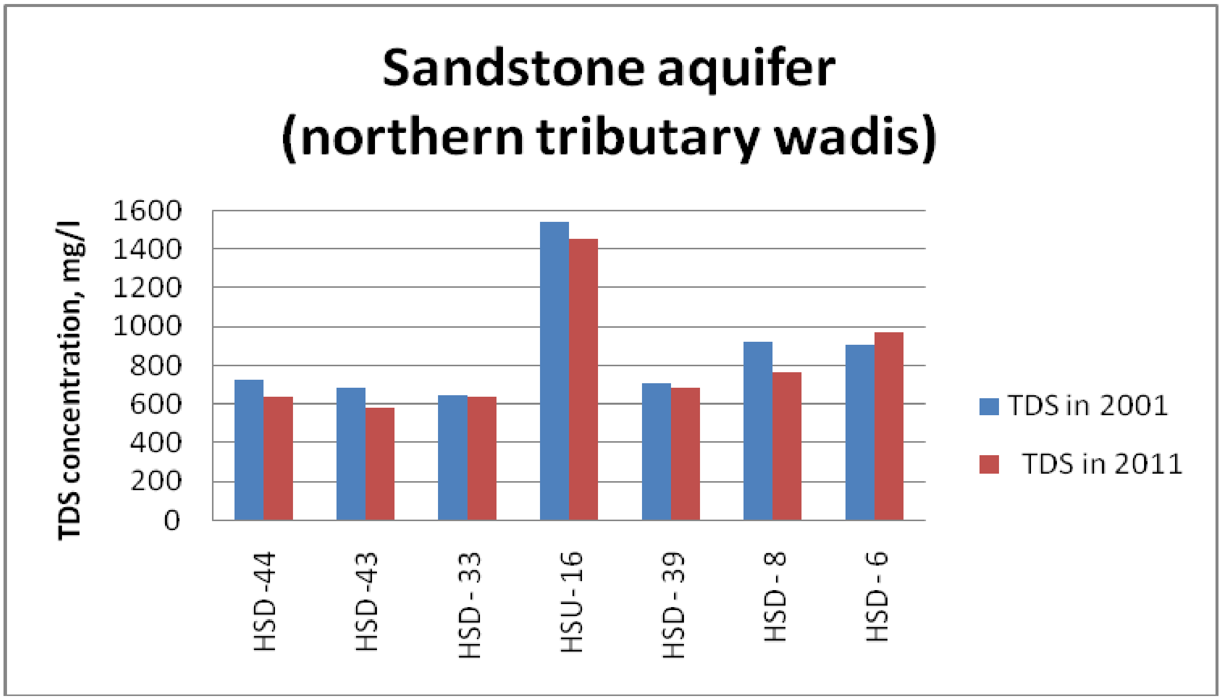

Figure 21. Sandstone aquifer (northern tributary wadis): Variations in TDS concentrations between 2001 and 2011

All nine water samples collected in the **southern tributary wadis** (HSD-12, HSD-2, HSD-1, HSD-3, HSU-10, HSU-14, and HSU-58. HSU-30 and HSU-50) show a decrease in groundwater salinity over the last decade as shown in Figure 22.

This pattern reflects an increase of fresh groundwater recharge along the southern tributary wadis during the last decade. An analysis of the long term groundwater-level monitoring records is required to support this hypothesis.

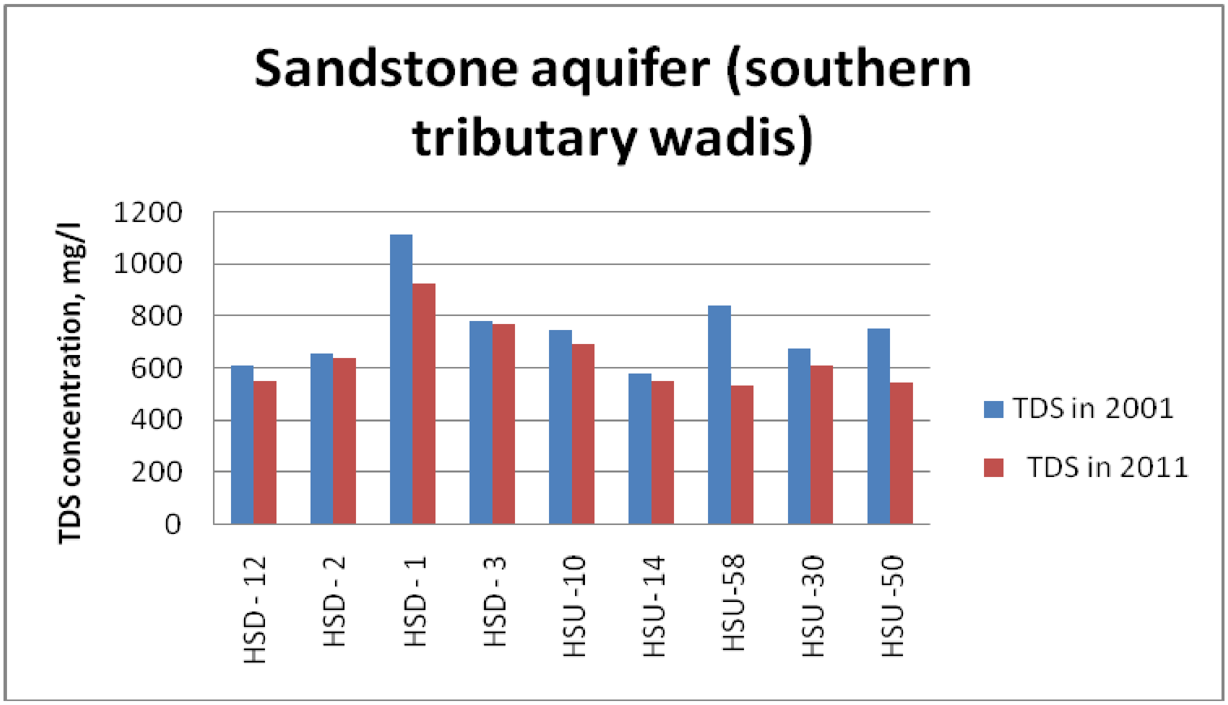

Figure 22. Sandstone aquifer (southern tributary wadis): Variations in TDS concentrations between 2001 and 2011

8 GROUNDWATER QUALITY ASPECTS

Hydrochemical conditions discussed in the preceding sections are described in terms of groundwater salinity and composition since the term quality is meaningless if not related to specific purpose of water use.

The great majority of water wells located in Wadi Hadhramawt is used for irrigation. The suitability of groundwater for irrigation is contingent on the effects of mineral constituents of the water on both the plant and the soil. The suitability of irrigation water is usually estimated from calculation of an empirically derived Sodium Adsorption Ratio (SAR). It indicates the degree to which cation exchange reactions occur in the soil. SAR should remain low enough so that Na occupies a low portion of the exchange complex. The structure and drainage properties of most soils remain good when SAR values remain below 10. All the samples analyzed by KOMEX in 2001 were suitable for irrigation with respect to the sodium hazard, however several water samples indicated high salinity hazard for the soil.

A total of 105 water samples collected by NWRA in 2011 from irrigation wells have been evaluated in terms of salinity and sodium hazards for the soil as tabulated in **Annex 8**. All the analyzed samples show the low sodium hazard for irrigation, except for sample HSD-216 which indicates medium sodium hazard (SAR = 11.5). At the same time, however, 99% of analyzed samples indicate high (EC = 750-2250 µS/cm) and very high (EC > 2250 µS/cm) salinity hazard to the soil.

Sustainable supply of population with water of reasonable quality is a top priority challenge because an access to good quality water is a fundamental human right, almost a "right to life" issue since clean drinking water plays a crucial role in the health of a community. For this reason, the water samples collected by NWRA in 20011 from 8 public wells supplying water to local communities in Wadi Hadhramawt are evaluated in terms of water suitability for drinking use. Appropriate guidelines set up by Yemen Standard for Drinking Water is used as basic parameters for comparison. All public water wells are completed in the sandstone aquifer. A summary of drinking-water quality classification for samples collected by both KOMEX in 2001 and NWRA in 2001 from these public water supply wells are given in Table 3.

It is clear from Table 3 that none of the samples collected in 2011 were found to be above/higher than the relevant national Maximum Permissible Limits, while most of the samples have concentrations higher than the national Maximum Desirable Limits. One sample, collected from well EU-201 owned by the Qawdah Water Supply Project (sample ID HSU-201), shows concentrations of almost all major ions higher than those set up as national MDL limits.

In general, the fresh water public wells show rather stable chemical composition in time, likely due to proper borehole design which prevents possible contamination from shallower aquifers.

Table 3. Chemical composition of groundwater supplying from public wells compared with the Yemen Standard for Drinking Water

Well ID	Aquifer	Year			Concentrations, mg/l											Remark
				EC, µS/cm	TDS	Ca	Mg	Na	K	HCO_3	Cl	SO_4	NO_3	Fe	F	
			MPL - YS	2500	1500	200	150	400	12	500	600	400	50	1	1.5	
			MDL-YS	1000	650	75	30	200	8	150	200	200	10	0.3	0.5	
D-785	Sandstone	2001		850	687	76	26	80	9	299	83	102	10	0.00	0.48	Tarim Water Supply Project
		2011	MPL= maximum	901	586	73	42	55	5	260	71	110	8.4	0.09	0.61	
D-778	Sandstone	2001	permissible limit	870	726	72	29	80	9	311	101	99	24	0.00	0.53	Tarim Water Supply Project
		2011		981	638	84	41	62	6.2	253	88	130	10.1	0.07	0.65	
D-1127	Sandstone	2001	MDL=maximum	860	622	82	41	29	7	287	87	79	9	0.20	0.67	NWSA-Seyun
		2011	desirable limit	772	502	78	32	40	7.3	238	75	83	2.6	0.64	0.54	
D-1133	Sandstone	2001		760	538	80	32	24	7	281	76	34	1	1.57	0.44	NWSA-Seyun
		2011	YS= Yemen	980	637	87	40	58	7.8	244	92	133	2.6	0.01	0.91	
U-1346	Sandstone	2001	Standard for	830	577	68	31	48	10	302	46	69	3	0.10	0.81	Wadi Bin Ali Water Supply Project
		2011	drinking water	842	547	68	41	49	5.2	288	61	90	2.6	0.06	1.3	
EU-201	Sandstone	2011		1530	995	85	51	120	8.9	221	240	200	12.8	0.1	0.98	Qawdah Water Supply Project
UA-380	Sandstone	2001		990	753	48	58	83	13	366	53	102	29	0.44	0.86	Hawrah Water Supply Project
		2011		839	545	55	57	55	5.3	278	66	110	27.3	0.00	1.23	
UA-221	Sandstone	2001		810	582	41	53	42	12	323	32	61	17	0.29	0.86	Al Ajlamah Water Supply Project
		2011		866	563	62	48	53	5	330	59	65	14.5	0.00	1.01	

Concentrations which exceed Maximum Permissible Limit of the Yemeni Standard for Drinking Water are highlighted in red

Concentrations which exceed Maximum Desirable Limit of the Yemeni Standard for Drinking Water are highlighted in orange

9 CONCLUSIONS

1. No significant changes in groundwater salinity patterns are reported between 2001 and 2011 except for an expansion of the elevated salinity areas located in the southern tributary wadis. The expansion of elevated salinity water did not link, however, with a general increase of chloride- and sodium-rich waters in these areas. There is some evidence of a decrease in salinity at the outlet of the main valley east of Tarim that might be explained by an increase of fresh groundwater recharge contributing to the main valley from Wadi Idim, especially due to the heavy flood event reported in 2008.

2. A lack of a general increase of chloride- and sodium-rich waters in the southern tributary wadis reflects continuation of groundwater recharge along these tributaries while irrigation return flows or other pollution sources did not significantly influence the recharged water. The general pattern of low salinity groundwater is modified when enters the main valley by mixing of different water types and probably by pollution in urban and agricultural lands.

3. The evolution of HCO_3-rich water to Ca/Mg-SO_4/Cl water between 2001 and 2011 is reported from some wells situated in the main valley, several northern tributaries and in the southern tributary Wadi Idim. This negative environmental trend very probably links to increasing land development (both urban and agricultural) and associated pollution.

4. In general, salinity of groundwater contained in the sandstone aquifer was reported to remain stable or even slightly decreasing during the last decade. This pattern reflects a stability or increase of fresh groundwater recharge along the tributary wadis between 2001 and 2011. At the same time, an increase of salinity in many locations was observed somewhere in groundwater contained in the shallower alluvium and conglomerate aquifers.

5. There is some evidence of significant reduction in the nitrate concentration between 2001 and 2011 in the area west of Al Qatn that likely reflects improving land development.

6. All the analyzed samples show the low sodium hazard for irrigation. At the same time, however, 99% of analyzed samples indicate high (EC = 750-2250 μS/cm) and very high (EC > 2250 μS/cm) salinity hazard to the soil.

7. None of the samples collected in 2011 from public supply wells were found to be above/higher than the relevant national Maximum Permissible Limits, while most of the samples have concentrations higher than the national MDL limits. One sample, collected from the well owned by the Qawdah Water Supply Project, shows concentrations of almost all major ions higher than those set up as national Maximum Desirable Limits. In general, the fresh water public wells show rather stable chemical composition in time, likely due to proper borehole design which prevents possible contamination from shallower aquifers.

10 RECOMMENDATIONS

1. Despite none of the water samples collected in 2011 were found to be above/higher than the relevant national MPL limits, the groundwater protection zones are recommended to establish around the municipal water supply wells/wellfields in accordance with NWRA guidelines in order to better protect the public sources of the drinking water supply to the provincial towns and local communities in Wadi Hadhramawt. Adequate land-use restriction measures would be implemented inside these zones in cooperation with the Local Water and Sanitation Corporation and administration of the Hadhramawt Governorate. The land-use restrictions within the protection zones would be as large as necessary for a safeguarding the public sources of drinking water and, on the other hand, to be as small as possible for avoiding inadequate inconveniences for neighboring farmers.

2. It is recommended that the adequate water-quality monitoring network should be established in Wadi Hadhramawt. The number and location of the water-quality observation wells should be selected based on the following major criteria: (a) these stations should be operating public wells intended for drinking supply; (b) several monitoring stations should be established upstream of the public wells in order to measure the quality of water moving to the production wells and to support in establishing groundwater protection zones; (d) several monitoring stations should be established downstream of the main pollution sources in order to measure the development of the possible plumes of contamination.

3. A thorough inventory of the potential pollution sources would be carried out throughout the target area with the specific reference to: (a) traditional cess-pits used for domestic and animal wastes; (b)

agricultural chemicals applied in the large farms; (c) petrol stations; (d) municipal waste disposals; and (e) oilfield wastes.

4. Available long-term monitoring records of groundwater level should be collected and analyzed in order to establish correlation between the temporal variations of recharge and changes in groundwater salinity in different parts of Wadi Hadhramawt.

5. Major outputs of this technical report would be incorporated in the ongoing Water Resources Management Plan for Wadi Hadhramawt.

REFERENCES

1. **KOMEX, 2002.** *Water Resources Management Studies in the Hadramaut Region*. Draft Final Report. Volume 4. Appendix VI: Water Quality and Pollution.

2. **NWRA, 2011.** NPIWRM database.

3. **WRAY-35, 1995.** *The Water Resources of Yemen: A Summary and Digest of Available Information*. Authors: Jac A.M. van der Gun and A.A.Ahmed.

ANNEX 1:

Summary of KOMEX chemical analyses (2001)

No.	ID No.	UTM E	UTM N	EC, µS/cm	Concentrations, mg/l														
					Ca	Mg	Na	K	CO_3	HCO_3	Cl	SO_4	NO_3	NO_2	NH_4	Fe	F	PO_4	TDS
1	D48	260698	1769226	2320	146	88	260	8	0	296	429	366	27	0.001	0.09	0.05	0.55	0.005	1621
2	D510	283730	1766678	640	58	28	20	12	0	238	59	15	0	0.000	0.00	2.06	0.61	0.000	433
3	D521	285809	1766998	2890	196	148	200	19	0	250	653	292	25	0.000	0.01	0.25	0.84	0.005	1786
4	D523	285595	1766702	1820	136	75	123	16	0	262	309	221	14	0.000	0.02	0.20	0.92	0.000	1157
5	D534	283185	1767351	3430	240	166	300	25	0	238	865	425	22	0.004	0.01	0.39	0.83	0.000	2282
6	D560	285049	1761695	940	86	32	59	15	0	256	120	87	2	0.001	0.02	0.05	0.83	0.005	657
7	D565	286294	1761989	1670	122	61	142	13	0	281	295	175	23	0.000	0.02	0.00	0.83	0.005	1114
8	D566	286338	1762165	1020	76	60	70	12	0	293	122	125	19	0.000	0.02	0.20	0.84	0.005	779
9	D602	289302	1766804	850	34	54	45	11	0	278	80	49	4	0.000	0.03	0.25	1.04	0.005	555
10	D627	287930	1770176	1420	96	68	110	17	0	314	203	179	4	0.000	0.00	0.05	0.81	0.014	993
11	D636	286993	1770172	950	82	35	74	16	0	271	127	100	2	0.000	0.00	0.00	0.68	0.000	707
12	D660	280501	1772933	2290	158	70	260	13	0	244	443	336	50	0.000	0.00	1.47	0.64	0.005	1576
13	D670	285969	1773853	6440	441	363	600	24	0	250	1470	1321	46	0.000	0.00	0.20	0.76	0.009	4515
14	D684	283039	1773073	1530	118	52	119	11	0	265	240	166	31	0.000	0.00	0.15	0.60	0.009	1003
15	D719	285867	1775037	13150	862	649	1600	33	0	366	3631	2236	52	0.004	0.00	0.74	0.84	0.005	9430
16	D771	283672	1774873	1290	92	41	140	10	0	256	243	216	24	0.008	0.02	0.10	0.59	0.005	1024
17	D778	285495	1780023	870	72	29	80	9	0	311	101	99	24	0.001	0.00	0.00	0.53	0.005	726
18	D785	284086	1781236	850	76	26	80	9	0	299	83	102	10	0.004	0.04	0.00	0.48	0.009	687
19	D859	292642	1773227	4620	267	181	555	53	0	342	975	1151	3	0.004	0.00	0.10	0.99	0.005	3528
20	D863	294390	1772430	1310	72	43	140	17	0	281	125	213	0	0.003	0.01	0.44	0.83	0.009	892
21	D905	301569	1776048	1750	84	77	199	25	0	342	234	358	4	0.003	0.02	0.64	1.05	0.009	1324
22	D960	287500	1778435	820	68	31	80	9	0	275	80	91	13	0.003	0.02	0.20	0.55	0.000	647
23	D978	291773	1775680	3530	192	154	460	27	0	268	792	614	34	0.011	0.00	0.09	0.79	0.005	2543
24	D995	297255	1778917	6920	216	423	773	53	0	354	1383	1807	12	0.004	0.00	0.20	1.05	0.014	5022
25	U007	261409	1764711	1770	140	67	150	15	0	311	278	223	11	0.000	0.10	0.25	0.66	0.000	1196
26	U1017	226302	1758866	2210	127	74	184	16	0	348	319	259	137	0.001	0.00	0.69	0.84	0.005	1466
27	U1046	220074	1755342	2550	147	62	255	18	0	311	447	312	24	0.000	0.32	0.49	0.78	0.023	1579
28	U1071	235598	1755562	5200	185	117	692	26	0	342	1344	528	11	0.001	0.00	0.05	0.69	0.005	3246
29	U1091	235793	1753351	1500	100	56	127	14	0	342	138	235	19	0.001	0.16	0.05	0.71	0.009	1033

No.	ID No.	UTM E	UTM N	EC, μS/cm	Concentrations, mg/l														
					Ca	Mg	Na	K	CO_3	HCO_3	Cl	SO_4	NO_3	NO_2	NH_4	Fe	F	PO_4	TDS
30	U1104	233253	1749039	1050	76	50	84	12	0	372	160	115	7	0.000	0.00	0.25	0.85	0.000	876
31	U1113	234878	1753813	1230	91	41	96	13	0	366	110	139	20	0.000	0.00	0.00	0.75	0.009	877
32	U1200	230954	1752730	1300	65	61	123	14	0	342	124	160	20	0.001	0.25	0.00	0.67	0.005	910
33	U1210	227691	1752415	1310	91	48	123	13	0	360	110	106	230	0.003	0.00	0.15	0.62	0.014	1082
34	U1253	228320	1753793	4760	345	204	347	22	0	305	1241	503	219	0.008	0.00	0.29	0.75	0.005	3187
35	U1293	225047	1754513	1360	83	50	120	14	0	329	160	155	18	0.001	0.31	0.29	0.69	0.000	930
36	U1317	247008	1755248	1060	88	31	67	13	0	314	115	109	3	0.001	0.00	0.44	0.60	0.000	743
37	U1342	249353	1752227	970	95	22	60	11	0	305	89	87	3	0.001	0.00	0.25	0.71	0.000	673
38	U1345	250611	1751138	780	64	31	43	12	0	287	44	66	4	0.003	0.00	0.15	0.94	0.000	552
39	U1346	251205	1748504	830	68	31	48	10	0	302	46	69	3	0.000	0.00	0.10	0.81	0.000	577
40	U1351	214342	1768057	1400	78	73	105	13	0	250	160	282	6	0.005	0.00	0.05	0.91	0.000	969
41	U1359	259804	1758047	1020	76	44	73	12	0	397	60	100	8	0.001	0.01	0.00	0.93	0.000	772
42	U1378	218042	1739647	1150	72	50	84	16	0	299	74	211	6	0.001	0.09	0.00	1.08	0.009	815
43	U167	259174	1762388	1980	132	111	150	21	0	336	208	460	11	0.009	0.00	0.69	0.67	0.009	1431
44	U175	256838	1761844	2000	84	103	200	16	0	354	320	262	49	0.008	0.10	0.25	0.63	0.005	1389
45	U207	261189	1762013	1450	124	62	104	13	0	329	184	208	2	0.000	0.13	0.29	0.63	0.000	1028
46	U245	253362	1760846	2320	140	91	240	15	0	336	424	253	24	0.009	0.00	0.29	0.74	0.000	1524
47	U294	251581	1765359	7260	353	336	1020	30	0	366	2224	925	27	0.000	0.04	0.00	0.88	0.005	5282
48	U328	252153	1761266	1610	112	72	120	13	0	348	202	230	14	0.000	0.07	0.05	0.81	0.000	1111
49	U329	252360	1760944	5670	176	274	680	28	0	336	1199	1028	30	0.003	0.00	0.15	0.79	0.000	3752
50	U423	247537	1756530	1480	120	48	150	11	0	372	167	211	10	0.009	0.00	0.20	0.22	0.005	1090
51	U432	246085	1758488	4430	216	168	540	22	0	390	1334	415	26	0.006	0.00	0.05	0.15	0.023	3113
52	U460	247912	1758136	1350	120	48	120	11	0	342	163	172	11	0.003	0.43	0.39	0.17	0.009	988
53	U466	250468	1759975	1730	130	66	150	13	0	323	257	200	22	0.000	0.14	0.34	0.65	0.005	1163
54	U523	247479	1760986	4070	180	161	480	22	0	317	862	643	26	0.000	0.03	0.59	0.83	0.009	2693
55	U524	247533	1760768	3930	160	166	480	24	0	329	830	636	29	0.000	0.00	0.69	0.79	0.000	2656
56	U531	247035	1762913	2950	184	115	320	18	0	299	566	528	25	0.005	0.19	0.39	0.68	0.005	2058

No.	ID No.	UTM E	UTM N	EC, µS/cm	Concentrations, mg/l														
					Ca	Mg	Na	K	CO_3	HCO_3	Cl	SO_4	NO_3	NO_2	NH_4	Fe	F	PO_4	TDS
57	U540	250734	1765258	6160	305	284	800	28	0	427	1730	1028	27	0.003	0.00	0.05	0.85	0.000	4630
58	U552	249248	1767662	3450	232	154	380	17	0	250	650	651	47	0.000	0.00	0.00	0.75	0.009	2382
59	U554	249189	1767216	3380	208	142	260	17	0	268	639	638	45	0.000	0.07	0.00	0.67	0.014	2219
60	U558	249336	1768707	2270	176	106	260	16	0	262	452	451	43	0.023	0.02	0.20	0.67	0.000	1767
61	U605	252796	1769850	2350	160	84	240	14	0	250	410	342	42	0.004	0.00	0.00	0.64	0.014	1543
62	U606	252937	1768813	3830	204	163	490	19	0	329	771	713	50	0.008	0.00	0.59	0.77	0.000	2741
63	U656	244164	1764474	5270	369	303	580	23	0	366	1404	887	42	0.000	0.04	0.00	0.79	0.009	3974
64	U675	243241	1764562	1160	96	41	100	9	0	268	139	142	27	0.005	0.14	0.10	0.62	0.009	824
65	U730	239742	1755477	2410	80	99	300	13	0	354	431	296	25	0.000	0.00	0.10	0.67	0.000	1598
66	U77	256983	1766878	4100	186	148	540	14	0	299	916	623	21	0.001	0.09	0.00	0.64	0.005	2748
67	U781	241593	1763527	1580	100	75	124	13	0	262	220	283	18	0.000	0.00	0.34	0.73	0.009	1096
68	U804	240856	1761581	4580	240	279	398	23	0	268	1280	468	60	0.000	0.25	0.34	0.80	0.018	3018
69	U830	240638	1761740	6280	289	242	692	23	0	268	1337	913	57	0.000	0.00	0.54	0.85	0.009	3821
70	U861	237542	1761781	1480	88	67	105	23	0	275	199	158	32	0.003	0.00	0.15	0.71	0.009	946
71	U884	233291	1763352	1080	73	42	84	10	0	268	113	104	17	0.004	0.00	0.15	0.72	0.009	713
72	U90	255655	1765821	7090	297	312	900	33	0	390	1716	991	24	0.000	0.05	0.00	0.85	0.009	4665
73	U940	237004	1758824	3300	165	111	366	21	0	323	688	430	15	0.001	0.00	0.34	0.81	0.005	2121
74	U946	234946	1755797	2300	94	78	225	16	0	384	408	239	14	0.001	0.00	0.39	0.67	0.005	1459
75	UA1	207773	1753158	7980	248	248	1209	32	0	268	1709	1545	44	0.009	0.01	0.78	0.68	0.000	5305
76	UA124	218289	1755265	6820	251	193	1070	25	0	403	1255	1308	122	0.004	0.34	0.25	0.92	0.009	4628
77	UA131	218660	1755431	2100	112	61	249	18	0	311	319	290	26	0.064	0.29	0.54	0.72	0.027	1387
78	UA135	213025	1739052	1110	82	50	90	12	0	366	78	122	40	0.000	0.00	0.39	0.88	0.000	842
79	UA136	211499	1740163	710	52	43	34	10	0	372	25	45	20	0.000	0.00	0.29	0.71	0.000	602
80	UA167	207149	1741504	930	43	52	75	14	0	311	53	109	16	0.001	0.00	0.20	0.86	0.005	674
81	UA173	207594	1744333	1550	100	64	135	16	0	256	202	315	12	0.000	0.00	0.15	0.80	0.005	1101
82	UA216	212780	1746538	950	40	54	63	12	0	317	46	100	23	0.001	0.00	0.00	0.85	0.005	655

No.	ID No.	UTM E	UTM N	EC µS/cm	Concentrations, mg/l														
					Ca	Mg	Na	K	CO_3	HCO_3	Cl	SO_4	NO_3	NO_2	NH_4	Fe	F	PO_4	TDS
83	UA221	212786	1745848	810	41	53	42	12	0	323	32	61	17	0.001	0.00	0.29	0.86	0.005	582
84	UA281	222622	1749983	2330	132	78	255	16	0	348	468	177	18	0.000	0.27	0.05	0.75	0.005	1493
85	UA29	208703	1750076	4070	164	154	525	23	0	293	539	974	89	0.004	0.00	0.44	0.78	0.005	2761
86	UA292	224784	1747155	2280	116	78	225	14	0	403	347	223	31	0.001	0.01	0.20	0.74	0.005	1438
87	UA307	225719	1749114	1480	83	55	112	12	0	354	177	118	20	0.024	0.13	0.39	0.68	0.005	932
88	UA330	225420	1752900	5960	479	174	555	23	0	439	1326	627	37	0.337	0.00	0.29	0.76	0.439	3663
89	UA337	218905	1750251	1490	75	42	138	14	0	329	152	209	15	0.003	0.20	0.25	0.76	0.005	977
90	UA380	210254	1738403	990	48	58	83	13	0	366	53	102	29	0.000	0.01	0.44	0.86	0.000	753
91	UA43	211332	1753276	2200	94	89	277	17	0	311	344	441	33	0.003	0.00	0.44	0.77	0.000	1607
92	UA79	216986	1750051	1450	74	49	178	16	0	342	156	275	20	0.001	0.05	0.34	0.72	0.009	1109
93	UA84	216721	1750709	4330	243	125	443	23	0	342	638	953	31	0.003	0.23	0.15	0.86	0.005	2799
94	D1	262142	1764558	1420	94	64	118	11	0	348	188	204	18	0.008	0.04	0.05	0.87	0.000	1045
95	D1001	296760	1779994	960	79	46	62	12	0	299	76	125	11	0.003	0.01	0.25	0.51	0.000	712
96	D1016	302003	1779322	10000	361	466	1388	60	0	329	2460	1953	8	0.000	0.12	0.29	0.79	0.005	7026
97	D1031	301194	1782492	1170	72	65	99	14	0	317	85	193	74	0.000	0.00	0.05	0.36	0.000	919
98	D1061	302620	1785482	5820	365	291	637	27	0	409	1283	1338	7	0.000	0.12	0.15	0.65	0.005	4357
99	D1062	302868	1785089	3530	216	151	377	22	0	354	791	655	8	0.000	0.09	0.15	0.60	0.009	2575
100	D1076	303966	1785839	1170	64	59	121	16	0	326	135	181	6	0.000	0.15	0.25	0.67	0.014	911
101	D1127	264484	1762841	860	82	41	29	7	0	287	87	79	9	0.001	0.10	0.20	0.67	0.005	622
102	D1133	265285	1760747	760	80	32	24	7	0	281	76	34	1	0.001	0.12	1.57	0.44	0.009	538
103	D1180	286356	1757638	1000	94	60	75	19	0	293	168	118	32	0.005	0.18	0.05	0.94	0.000	861
104	D1186	286333	1756930	820	60	36	42	17	0	287	71	62	1	0.006	0.00	0.98	0.85	0.023	579
105	D1215	288404	1754068	800	60	39	44	8	0	329	55	63	7	0.001	0.00	0.10	1.03	0.000	607
106	D1225	270497	1732721	1210	97	41	64	9	0	384	96	140	10	0.013	0.00	0.49	0.78	0.023	842
107	D1227	286328	1754689	900	77	38	58	14	0	299	92	101	4	0.004	0.01	0.78	0.86	0.005	686
108	D1232	296802	1788309	800	49	40	44	8	0	305	55	83	3	0.003	0.01	0.20	0.84	0.000	588

No.	ID No.	UTM E	UTM N	EC µS/cm	Concentrations, mg/l														
					Ca	Mg	Na	K	CO_3	HCO_3	Cl	SO_4	NO_3	NO_2	NH_4	Fe	F	PO_4	TDS
109	D1234	286501	1781390	750	42	38	36	7	0	262	44	71	1	0.001	0.00	0.10	0.74	0.005	502
110	D1236	275155	1780753	600	48	31	26	5	0	220	35	46	2	0.003	0.00	0.05	0.63	0.000	413
111	D230	266566	1766391	1540	122	60	130	12	0	299	261	160	3	0.000	0.06	0.05	0.92	0.005	1049
112	D245	266207	1765288	1600	118	70	160	8	0	320	259	191	13	0.028	0.01	0.00	0.64	0.005	1139
113	D248	267973	1764826	1010	92	35	58	13	0	256	115	143	0	0.000	0.09	0.20	0.89	0.000	714
114	D253	266795	1765222	1780	110	88	160	11	0	287	268	279	14	0.013	0.04	0.15	0.93	0.000	1218
115	D256	267600	1765963	4470	303	189	440	22	0	293	1108	575	10	0.001	0.01	0.00	0.90	0.000	2940
116	D26	261661	1766247	2540	120	115	270	16	0	305	504	313	18	0.063	0.01	0.25	0.80	0.005	1662
117	D268	268252	1767848	1050	78	47	34	9	0	253	128	111	22	0.005	0.00	0.20	0.55	0.000	682
118	D275	267342	1770241	7620	337	274	960	18	0	244	1950	745	21	0.004	0.03	0.25	0.68	0.014	4550
119	D302	269896	1766643	6700	293	324	840	37	0	293	1664	1028	9	0.000	0.00	0.78	0.86	0.005	4491
120	D307	268045	1771986	4750	166	215	600	13	0	299	1173	453	19	0.008	0.05	0.88	0.62	0.018	2940
121	D311	265500	1774520	1660	106	73	140	7	0	271	269	179	29	0.004	0.08	0.10	0.57	0.018	1077
122	D317	267626	1774493	2070	138	85	160	7	0	271	342	360	36	0.004	0.11	0.25	0.00	0.018	1401
123	D327	268793	1773381	2010	136	53	230	8	0	305	319	232	32	0.005	0.01	0.15	0.53	0.142	1317
124	D358	270858	1771275	4450	134	251	500	19	0	302	970	764	32	0.000	0.00	0.15	0.84	0.000	2973
125	D391	273740	1773903	2210	128	94	260	11	0	278	429	311	28	0.005	0.00	0.15	0.62	0.000	1540
126	D396	274524	1772879	6040	305	274	700	28	0	305	1515	689	34	0.000	0.07	0.00	0.79	0.005	3850
127	D406	275414	1773430	3730	162	191	440	15	0	271	950	467	30	0.000	0.04	0.15	0.81	0.000	2528
128	D458	277432	1767430	1300	116	46	96	15	0	290	170	147	0	0.000	0.00	0.54	0.69	0.005	881
129	D467	278385	1766972	980	76	36	58	13	0	293	109	81	1	0.000	0.00	0.64	0.86	0.000	669
130	D469	278110	1766085	1540	92	73	140	14	0	293	214	262	13	0.000	0.06	0.05	0.93	0.000	1102
131	D474	278562	1767342	1000	102	35	59	16	0	287	96	123	4	0.000	0.00	0.25	0.78	0.000	722
132	D479	279326	1769333	9410	489	423	1170	40	0	281	2439	1434	10	0.000	0.02	0.29	0.82	0.014	6287

ANNEX 2:

Sampling point locations (2011)

No.	Sample ID	Well ID	Site	UTM E	UTM N	Elevation, masl
1	HAD 200	ED -200	Al Hawir	265775	1765052	639
2	HSD 210	ED -210	Madooda	259873	1768159	658
3	HSD - 1	D565	Ba'lal	286294	1761989	660
4	HSD - 10	D627	Bit Jabeer	287930	1770176	640
5	HSD - 11	D1227	Mashaghah	286328	1754689	679
6	HSD - 12	D1215	Al Jawi	288404	1754068	682
7	HSD - 13	D1061	Qasam (Al Wastah)	302620	1785482	610
8	HSD - 14	D026	Alhomirat	261661	1766247	660
9	HSD - 15	D248	Mariama	267973	1764826	660
10	HSD - 16	D510	Al Garrah	283730	1766678	640
11	HSD - 17	D636	Ba Jel Hebal	286993	1770172	643
12	HSD - 19	D660	Rhwat Ma'iaz	280501	1772933	648
13	HSD - 2	D560	Ba'lal	285049	1761695	668
14	HSD - 22	D458	Wadi Harad	277432	1767430	659
15	HSD - 23	D479	Diar Aal Ghrieb	279326	1769333	632
16	HSD - 25	D358	Shagih	270858	1771275	650
17	HSD - 29	D311	Wadi Madr	265500	1774520	688
18	HSD - 3	D566	Ba'lal	286338	1762165	654
19	HSD - 31	D275	Salilah	267342	1770241	660
20	HSD - 33	D960	Dammun (Al Mashrokhah)	287500	1778435	640
21	HSD - 35	D863	Mishtah	294390	1772430	621
22	HSD - 38	D245	Al Hawir	266207	1765288	660
23	HSD - 39	D1001	Al Qariah	296760	1779994	612
24	HSD - 4	D523	Al Ghoraf	285595	1766702	647
25	HSD - 40	D268	Mariama	268252	1767848	640
26	HSD - 41	D001	Al Saheel	262142	1764558	660
27	HSD - 42	D256	Mariama	267600	1765963	660
28	HSD - 46	D1133	Jathmah	265285	1760747	702
29	HSD - 48	D230	Al Hawir	266566	1766391	660
30	HSD - 5	D521	Al Ghoraf	285809	1766998	650
31	HSD - 6	D1076	Qasam (Al Wastah)	303966	1785839	610
32	HSD - 7	D1062	Qasam (Al Husson)	302868	1785089	602
33	HSD - 8	D1031	qasam (Wadi Hussin)	301194	1782492	609
34	HSD - 9	D602	Al Suwayri	289302	1766804	638
35	HSD -18	D1236	Wadi Thibi	275155	1780753	721
36	HSD -20	D474	Al Saheel Al Sharqi	278562	1767342	670
37	HSD 201	ED -201	Salela	263262	1767844	640
38	HSD 202	ED -202	Salela	267089	1770290	650
39	HSD 203	ED -203	Treem	285717	1774767	674
40	HSD 204	ED -204	Treem	285820	17750263	609
41	HSD 205	ED -205	Jathmah	263811	1763243	660
42	HSD 206	ED -206	Tarba	274880	176948	635

No.	Sample ID	Well ID	Site	UTM E	UTM N	Elevation, masl
43	HSD 207	ED -207	Tarba	275485	1769846	650
44	HSD 208	ED -208	Tarba	280334	176985	637
45	HSD 209	ED -209	Gufel AL zeema	260795	1768288	659
46	HSD -21	D469	Ghanimah	278110	1766085	656
47	HSD 211	ED -211	Al arath Al Sharqi	261396	1768496	642
48	HSD 215	ED -215	AL heemrat	259620	1765390	652
49	HSD 217	ED -217	AL heemrat	260427	1765462	660
50	HSD -24	D467	Al Ogdah	278385	1766972	650
51	HSD -27	D391	Seheel Abdillah	273740	1773903	672
52	HSD -28	D406	Mogaibel	275414	1773430	675
53	HSD -30	D317	Wadi Madr	267626	1774493	675
54	HSD -32	D978	Al Jheel	291773	1775680	620
55	HSD -34	D1234	Wadi Dammoun	286501	1781390	690
56	HSD -36	D048	Aal bin Saeed	260698	1769226	688
57	HSD -37	D771	Al Ketbah	283672	1774873	640
58	HSD -43	D785	Dammun	284086	1781236	659
59	HSD -44	D778	Dammun	285495	1780023	660
60	HSD -45	D1127	Jathmah	264484	1762841	691
61	HSD -47	D1225	Ghayil Omer	270497	1732721	744
62	HSD212	ED -212	Shibam	249182	1761443	670
63	HSD213	ED -213	Shibam	247184	1761438	674
64	HSD214	ED -214	AL heemrat	259522	1765127	661
65	HSD216	ED -216	AL heemrat	260610	1766191	664
66	HSU - 2	UA-46	Hainin	212322	1753103	714
67	HSU -10	U1317	Mawshah	247008	1755248	693
68	HSU -11	U432	Arshan	246085	1758488	706
69	HSU- 13	U1345	Al Gharib	250611	1751138	699
70	HSU- 14	U1346	Al Rawdhah	251205	1748504	720
71	HSU- 15	U606	Ar Rwadhah	252937	1768813	687
72	HSU- 16	U605	Ar Rwadhah	252796	1769850	705
73	HSU- 17	U558	Al Suhill Village	249336	1768707	698
74	HSU- 19	U554	Al Qufl Village	249189	1767216	679
75	HSU 200	EU -200	ALGhahr	207773	1753158	720
76	HSU 201	EU -201	Qawodhah	207428	1744202	764
77	HSU 203	EU -203	Khobet	215626	1771548	766
78	HSU 204	EU -204	AL saheel	262513	1764590	655
79	HSU 205	EU -205	Madooda	259559	1767785	661
80	HSU -29	U077	Ardh Al Gibli	256983	1766878	687
81	HSU -30	UA-167	Al Qofol	207149	1741504	744
82	HSU -31	U007	Al Saheel	261409	1764711	670
83	HSU -35	U1253	Kross Al Mashaikh	228320	1753793	686

No.	Sample ID	Well ID	Site	UTM E	UTM N	Elevation, masl
84	HSU -36	U1071	Hadiyah	235598	1755562	697
85	HSU -42	U730	Aiqran	239742	1755477	704
86	HSU -47	UA -282	Barwaj	222678	1749780	697
87	HSU -48	U884	Al Jowadah	233291	1763352	720
88	HSU- 49	Ua 216	Al Ajlaniah	212780	1746538	719
89	HSU- 5	U1293	Al Fort	225047	1754513	708
90	HSU -50	UA-380	Hawrah	210254	1738403	768
91	HSU -51	UA-221	Al Ajlaniah	212786	1745848	739
92	HSU -52	U1046	Anibithah	220074	1755342	729
93	HSU -53	UA-124	Shib Aal Nohid	218289	1755265	704
94	HSU -54	U940	Trefah	237004	1758824	694
95	HSU -56	U1017	Zikikah	226302	1758866	715
96	HSU -57	U1351	Wadi Khwonab	214342	1768057	671
97	HSU -6	UA-330	Barwaj	225420	1752900	677
98	HSU- 7	UA-337	Mudhor	218905	1750251	702
99	HSU-12	U523	Al Hazm	247479	1760986	673
100	HSU-18	U552	Al qufl Village	249248	1767662	698
101	HSU-20	U540	Bahirah	250734	1765258	670
102	HSU-202	EU -202	Qarew	252152	1761265	688
103	HSU-21	U-294	Beherah	251581	1765359	664
104	HSU-22	U-531	Shibam	247035	1762913	695
105	HSU-23	U-781	Jojah	241593	1763527	706
106	HSU-24	U804	Al Aqad (Al Hemah)	240856	1761581	690
107	HSU-26	U-466	Al Howtah	250468	1759975	681
108	HSU-27	U-329	Qarew	252360	1760944	688
109	HSU-3	Ua-29	Alsahbi	208703	1750076	725
110	HSU-32	U946	As Sbahkh	234946	1755797	692
111	HSU-33	U1210	Al Qaten	227691	1752415	713
112	HSU-34	U1200	Al Anin	230954	1752730	704
113	HSU-37	U861	Howilah	237542	1761781	690
114	HSU-38	U167	Sharqi Tarees	259174	1762388	683
115	HSU-41	U175	Al Ghorfah	256838	1761844	684
116	HSU-43	U1113	Lasarbah	234878	1753813	695
117	HSU-44	U207	Wadi Tarees	261189	1762013	668
118	HSU-46	UA-292a	Al Shikilan	224839	1747125	704
119	HSU-57	U1359	Wadi Tha'labah	259804	1758047	698
120	HSU-58	UA-135	Hawrah (Shib Al Dhija')	213025	1739052	749
121	HSU-61	U1378	Manwoab	218042	1739647	695
122	HSU-8	UA-84	Nasriah	216721	1750709	704
123	HSU-9	U423	Al Sofol	247537	1756530	701

ANNEX 3:

Sampling points (2011): Well and aquifer performance data

Sample ID	Well ID	Date of sampling	Type of water point	Total depth, m	Casing interval, m		Aquifer under abstraction	Field measurements		Water use
					from	to		pH	EC, µS/cm	
HSD - 14	**D026**	4/16/2011	Borehole	245	0	150	Sandstone	7.06	3402	Irrigation
HSD -36	**D048**	4/22/2011	Borehole	154	No data	No data	Sandstone	7.06	2770	Irrigation
HAD 200	**ED -200**	4/25/2011	Borehole	No data	No data	No data	No data	7.2	1500	No data
HSD 201	**ED -201**	4/26/2011	Borehole	No data	No data	No data	No data	7.43	1694	Irrigation
HSD 202	**ED -202**	4/28/2011	Borehole	No data	No data	No data	No data	7.36	7380	Irrigation
HSD 203	**ED -203**	4/28/2011	Dug/Bore	No data	No data	No data	No data	7.61	5750	Irrigation
HSD 204	**ED -204**	4/28/2011	Borehole	117	No data	No data	No data	7.87	1380	Irrigation
HSD 205	**ED -205**	4/30/2011	Borehole	No data	No data	No data	No data	7.66	1043	other
HSD 206	**ED -206**	5/1/2011	Borehole	150	No data	No data	No data	6.6	3950	Irrigation
HSD 207	**ED -207**	5/1/2011	Borehole	No data	No data	No data	No data	7.06	8800	Irrigation
HSD 208	**ED -208**	5/2/2011	Borehole	No data	No data	No data	No data	6.88	18960	No data
HSD 209	**ED -209**	5/2/2011	Borehole	No data	No data	No data	No data	7.04	4800	Irrigation
HsD 210	**ED -210**	5/2/2011	Borehole	No data	No data	No data	No data	6.99	5100	Irrigation
HSD 211	**ED -211**	5/2/2011	Borehole	No data	No data	No data	No data	7.5	6280	Irrigation
HSD212	**ED -212**	5/3/2011	Duge/Bore	No data	No data	No data	No data	6.64	6830	Irrigation
HSD213	**ED -213**	5/3/2011	Borehole	60	No data	No data	No data	6.84	11400	Irrigation
HSD214	**ED -214**	5/3/2011	Borehole	No data	No data	No data	No data	6.69	8360	Irrigation
HSD 215	**ED -215**	5/3/2011	Borehole	No data	No data	No data	No data	6.85	4730	Irrigation
HSD216	**ED -216**	5/3/2011	Borehole	No data	No data	No data	No data	6.73	11210	Irrigation
HSD 217	**ED -217**	5/3/2011	Borehole	No data	No data	No data	No data	6.78	5000	Irrigation
HSU 200	**EU -200**	4/13/2011	Duge/Bore	No data	No data	No data	No data	6.91	No data	No data
HSU 201	**EU -201**	4/13/2011	Borehole	220	No data	12	Sandstone	6.94	1773	Supply
HSU-202	**EU -202**	4/23/2011	Borehole	60	No data	No data	No data	6.77	1992	Irrigation
HSU 203	**EU -203**	4/28/2011	No data	No data	No data	No data	No data	7.89	No data	No data
HSU 204	**EU -204**	4/29/2011	Borehole	73	No data	No data	No data	7.06	2360	Irrigation
HSU 205	**EU -205**	5/2/2011	Borehole	No data	No data	No data	No data	7.11	6180	Irrigation
HSU -29	**U077**	4/24/2011	Duge/Bore	60	No data	No data	Conglemerate	6.46	3770	Irrigation

Sample ID	Well ID	Date of sampling	Type of water point	Total depth, m	Casing interval, m from	Casing interval, m to	Aquifer under abstraction	Field measurements pH	Field measurements EC, μS/cm	Water use
HSU- 49	**UA 216**	4/26/2011	Duge/Bore	55	25	31	Conglemerate	7.25	1160	Irrigation
HSU -46	**UA -292a**	4/26/2011	Borehole	No data	No data	No data	No data	7.04	2.792	No data
HSU -47	**UA-282**	4/26/2011	Borehole	No data	No data	No data	No data	No data	No data	No data
HSU - 2	**UA-46**	4/13/2011	Borehole	No data	No data	No data	No data	7.09	3636	Irrigation
HSD - 41	**D001**	4/24/2011	Duge/Bore	60	No data	No data	Alluvium	6.82	1645	Irrigation
HSD - 39	**D1001**	4/24/2011	Borehole	170	0	80	Sandstone	6.98	1220	Irrigation
HSD - 8	**D1031**	4/13/2011	Duge/Bore	No data	21	51	Sandstone	7.17	669	Irrigation
HSD - 13	**D1061**	4/16/2011	Duge/Bore	85	No data	No data	Conglemerate	6.41	935	Irrigation
HSD - 7	**D1062**	4/13/2011	Duge/Bore	56	13	31	Conglemerate	7.14	5270	Irrigation
HSD - 6	**D1076**	4/13/2011	Duge/Bore	27	No data	No data	Sandstone	7.05	1669	Irrigation
HSD -45	**D1127**	4/27/2011	Borehole	119.5	No data	No data	Sandstone	7.38	800	Domestic
HSD - 46	**D1133**	4/27/2011	Borehole	166	0	69	Sandstone	7.4	965	Domestic
HSD - 12	**D1215**	4/16/2011	Borehole	160	0	50	Sandstone	7.16	892	Irrigation
HSD -47	**D1225**	5/2/2011	Spring	No data	No data	No data	No data	6.86	1052	Irrigation
HSD - 11	**D1227**	4/15/2011	Duge/Bore	56	0	42	Conglemerate	6.99	785	Irrigation
HSD -34	**D1234**	4/21/2011	Spring	No data	No data	No data	No data	7.69	824	Irrigation
HSD -18	**D1236**	4/16/2011	Spring	No data	No data	No data	No data	7.73	817	Irrigation
HSD - 48	**D230**	4/25/2011	Borehole	180	0	120	Sandstone	7.06	1766	Irrigation
HSD - 38	**D245**	4/23/2011	Borehole	208	0	100	Sandstone	7.39	1815	Irrigation
HSD - 15	**D248**	4/16/2011	Duge/Bore	44	No data	No data	Conglomerate	7.09	1403	others
HSD - 42	**D256**	4/26/2011	Duge/Bore	36	No data	No data	Alluvium	7.09	6120	Irrigation
HSD - 40	**D268**	4/24/2011	Borehole	180	0	119	Sandstone	7.03	2040	Irrigation
HSD - 31	**D275**	4/20/2011	Borehole	160	0	130	Sandstone	6.77	8240	Irrigation
HSD - 29	**D311**	4/20/2011	Borehole	80	0	40	Conglemerate	7.02	2364	Irrigation
HSD -30	**D317**	4/20/2011	Borehole	85	No data	No data	Conglemerate	6.97	2148	Irrigation
HSD - 25	**D358**	4/18/2011	Borehole	50	No data	No data	Sandstone	8.18	5130	Irrigation
HSD -27	**D391**	4/18/2011	Borehole	154	0	96	Sandstone	8.28	2616	Irrigation

Sample ID	Well ID	Date of sampling	Type of water point	Total depth, m	Casing interval, m		Aquifer under abstraction	Field measurements		Water use
					from	to		pH	EC, µS/cm	
HSD -28	**D406**	4/18/2011	Borehole	180	No data	No data	Sandstone	8.11	3942	Irrigation
HSD - 22	**D458**	4/19/2011	Duge/Bore	54	No data	No data	Conglomerate	7.23	1645	Irrigation
HSD -24	**D467**	4/19/2011	Duge/Bore	75	No data	No data	Sandstone	7.33	1368	Irrigation
HSD -21	**D469**	4/19/2011	Duge/Bore	53	No data	No data	Conglemerate	7.17	32.4	Irrigation
HSD -20	**D474**	4/14/2011	Dug well	50	No data	No data	Sandstone	7.12	1122	Irrigation
HSD - 23	**D479**	4/19/2011	Duge/Bore	48	No data	No data	Alluvium	6.9	9800	Irrigation
HSD - 16	**D510**	4/16/2011	Borehole	190	0	100	Sandstone	7.16	827	Irrigation
HSD - 5	**D521**	4/12/2011	Borehole	160	No data	No data	Sandstone	7.15	2430	Irrigation
HSD - 4	**D523**	4/12/2011	Borehole	192	0	100	Sandstone	7.23	1781	Irrigation
HSD - 2	**D560**	4/12/2011	Borehole	154	0	82	Sandstone	7.3	975	Irrigation
HSD - 1	**D565**	4/12/2011	Borehole	200	No data	No data	Sandstone	7.22	1408	Irrigation
HSD - 3	**D566**	4/12/2011	Borehole	150	0	24	Sandstone	7.26	1152	Irrigation
HSD - 9	**D602**	4/15/2011	Borehole	186	0	80	Sandstone	6.88	920	Irrigation
HSD - 10	**D627**	4/15/2011	Borehole	68	0	50	Conglemerate	6.97	2088	Irrigation
HSD - 17	**D636**	4/16/2011	Borehole	156	0	95	Sandstone	7.2	1329	Irrigation
HSD - 19	**D660**	4/16/2011	Duge/Bore	73	No data	No data	Sandstone	7.08	2250	Irrigation
HSD -37	**D771**	4/22/2011	Borehole	50	No data	No data	Sandstone	7.19	705	Irrigation
HSD -44	**D778**	4/27/2011	Borehole	133.4	0	52	Sandstone	7.4	946	Domestic
HSD -43	**D785**	4/27/2011	Borehole	198.5	0	118	Sandstone	7.57	800	Domestic
HSD - 35	**D863**	4/21/2011	Borehole	190	0	98	Sandstone	7.25	1056	Irrigation
HSD - 33	**D960**	4/21/2011	Borehole	65	0	60	Sandstone	7.25	1170	Irrigation
HSD -32	**D978**	4/21/2011	Borehole	40	0	24	Conglemerate	6.94	3961	Irrigation
HSU -31	**U007**	4/26/2011	Borehole	150	0	85	Sandstone	6.72	1912	Irrigation
HSU -56	**U1017**	4/27/2011	Borehole	250	0	190	Sandstone	7.06	3314	Irrigation
HSU -52	**U1046**	4/27/2011	Borehole	260	0	120	Sandstone	7.05	2442	Irrigation
HSU -36	**U1071**	4/24/2011	Dug well	27	No data	No data	No data	6.92	7590	Irrigation

Sample ID	Well ID	Date of sampling	Type of water point	Total depth, m	Casing interval, m		Aquifer under abstraction	Field measurements		Water use
					from	to		pH	EC, µS/cm	
HSU-43	**U1113**	4/25/2011	Borehole	160	0	78	Sandstone	7.16	1581	Irrigation
HSU-34	**U1200**	4/25/2011	Borehole	150	0	120	Sandstone	6.99	1691	Irrigation
HSU-33	**U1210**	25/42011	Borehole	154	No data	No data	Sandstone	6.91	1433	Irrigation
HSU -35	**U1253**	4/25/2011	Duge/Bore	53	No data	No data	No data	7	1484	Irrigation
HSU- 5	**U1293**	4/17/2011	Borehole	220	0	180	Sandstone	6.89	6120	Irrigation
HSU -10	**U1317**	4/17/2011	Borehole	100	0	50	Sandstone	7	583	Irrigation
HSU- 13	**U1345**	4/19/2011	Borehole	44	No data	No data	No data	7.18	468	Irrigation
HSU- 14	**U1346**	4/17/2011	Borehole	130	0	64	Sandstone	No data	564	Domestic
HSU -57	**U1351**	4/28/2011	Spring	No data	No data	No data	No data	7.58	1554	No data
HSU-57	**U1359**	4/30/2011	Duge/Bore	36	No data	No data	Sandstone	6.91	1283	Irrigation
HSU-60	**U1378**	4/28/2011	Spring		No data	No data	Alluvium	8.2	1181	Animal
HSU-38	**U167**	4/25/2011	Duge/Bore	37	No data	No data	Sandstone	6.62	1788	Irrigation
HSU-41	**U175**	4/25/2011	Dug well	23	No data	No data	Alluvium	7	3000	Irrigation
HSU-44	**U207**	4/25/2011	Duge/Bore	120	No data	No data	Sandstone	7.06	1150	Irrigation
HSU-21	**U-294**	4/19/2011	Duge/Bore	50	No data	No data	Alluvium	6.9	5370	Irrgation
HSU-27	**U-329**	4/23/2011	Dug well	20	No data	No data	Conglomerate	6.71	2192	Irrigation
HSU-9	**U423**	4/23/2011	Duge/Bore	35	No data	No data	Alluvium	7.06	1306	Irrigation
HSU -11	**U432**	4/17/2011	Duge/Bore	98	No data	No data	Conglemerate	7.07	2980	Irrigation
HSU-26	**U-466**	4/23/2011	Borehole	148	No data	No data	Sandstone	6.57	2179	Irrigation
HSU-12	**U523**	4/20/2011	Borehole	63	No data	No data	Conglemerate	7.03	1960	Irrigation
HSU-22	**U-531**	4/19/2011	Borehole	220	No data	No data	Sandstone	7.08	3315	Irrgation
HSU-20	**U540**	4/19/2011	Duge/Bore	62	No data	No data	Conglemerate	6.44	3085	Irrigation
HSU-18	**U552**	4/19/2011	Borehole	78	0	12	Conglemerate	6.78	1778	Irrigation
HSU- 19	**U554**	4/19/2011	Borehole	60	0	18	Conglemerate	6.88	3395	Irrigation
HSU- 17	**U558**	4/18/2011	Borehole	72	0	6	Sandstone	8.14	1195	Irrigation
HSU- 16	**U605**	4/18/2011	Borehole	173	No data	No data	Sandstone	8.29	1257	Irrigation
HSU- 15	**U606**	4/18/2011	Borehole	93	No data	No data	Conglemerate	8.02	1958	Irrigation

Sample ID	Well ID	Date of sampling	Type of water point	Total depth, m	Casing interval, m		Aquifer under abstraction	Field measurements		Water use
					from	to		pH	EC, µS/cm	
HSU -42	**U730**	4/25/2011	Borehole	160	0	80	Sandstone	7.03	2737	Irrigation
HSU-23	**U-781**	4/20/2011	Borehole		No data	No data	No data	6.69	1864	Irrigation
HSU-24	**U804**	4/20/2011	Borehole	123	0	60	Conglemerate	6.71	No data	Irrigation
HSU-37	**U861**	4/25/2011	Borehole	100	0	41	Sandstone	No data	1696	Irrigation
HSU -48	**U884**	4/26/2011	Dug well	32	No data	No data	No data	7.31	1102	Irrigation
HSU -54	**U940**	4/27/2011	Borehole	241	0	160	Sandstone	6.95	4782	Irrigation
HSU-32	**U946**	4/25/2011	Borehole	220	0	125	Sandstone	6.7	4106	Irrigation
HSU -53	**UA-124**	4/27/2011	Duge/Bore	52	No data	No data	Conglemerate	7.12	3474	Irrigation
HSU-58	**UA-135**	4/30/2011	Borehole	80	0	60	Sandstone	7.06	914	Irrigation
HSU -30	**UA-167**	4/23/2011	Borehole	160	0	100	Sandstone	7.02	1047	Irrigation
HSU -51	**UA-221**	4/26/2011	Borehole	150	0	80	Sandstone	7.24	957	Domestic
HSU -3	**UA-29**	4/13/2011	Dug well	35	No data	No data	No data	6.97	4872	Irrigation
HSU -6	**UA-330**	4/17/2011	Borehole	40	No data	No data	Conglemerate	6.8	5520	Other
HSU- 7	**UA-337**	4/17/2011	Borehole	150	0	135	Sandstone	7	2240	Irrigation
HSU -50	**UA-380**	4/26/2011	Borehole	156	0	81	Sandstone	7.61	1025	Supply
HSU-8	**UA-84**	4/17/2011	Borehole	130	0	80	No data	6.89	5130	Irrigation

Note: ID numbers of the wells previously sampled by KOMEX in 2001 are highlighted in **red**

ANNEX 4:

Summary of NWRA chemical analyses (2011)

Sample ID	pH	EC µS/cm	Concentration, mg/l												
			TDS	TH	TA	HCO_3	Cl	SO_4	F	Ca	Mg	Na	K	NO_3	Fe
HAD 200	7.2	1575	1024	640	213	260	211	255	0.94	135	73	92	4.1	5.3	0.20
HSD 210	6.99	5110	3322	1375	268	327	1054	800	1.21	216	203	679	18.8	17.6	0.01
HSD - 1	7.22	1420	923	492	205	250	195	195	1.16	97	61	117	7.7	12.3	0.03
HSD - 10	6.97	1897	1233	622	208	254	295	285	0.81	112	83	174	14.8	5.3	0.04
HSD - 11	6.99	975	634	362	213	259	95	115	0.62	85	36	64	8.9	2.2	0.03
HSD - 12	7.16	842	547	328	211	257	70	90	0.98	62	42	53	6.2	7.4	0.01
HSD - 13	6.41	973	632	381	230	281	83	110	0.82	79	45	59	5.9	13.2	0.01
HSD - 14	7.06	3100	2015	960	224	273	617	410	0.96	208	107	312	12.8	16.7	0.02
HSD - 15	7.09	1242	807	473	170	207	112	275	1.23	98	55	70	11.8	5.7	0.05
HSD - 16	7.16	712	463	279	174	212	69	70	0.77	76	22	39	8.1	2.2	0.06
HSD - 17	7.2	1171	761	392	182	222	152	155	0.95	83	45	96	12.4	2.2	0
HSD - 19	7.08	2140	1391	563	189	231	339	300	0.87	92	81	189	8	29.0	0.04
HSD - 2	7.3	984	640	362	194	236	117	100	1.11	70	45	60	9.6	27.3	0.03
HSD - 22	7.23	1465	952	432	214	261	183	225	0.94	68	64	106	9.6	8.4	0.00
HSD - 23	6.9	9020	5863	2886	239	291	2276	1220	1.47	450	428	1045	42	8.8	0.05
HSD - 25	8.18	4770	3101	1483	207	252	967	840	0.91	266	199	550	13	36.5	0.01
HSD - 29	7.02	2170	1411	722	192	234	336	315	0.90	154	82	160	8	22.4	0.00
HSD - 3	7.26	1186	771	448	214	261	139	165	1.19	79	61	79	7.6	12.3	0.01
HSD - 31	6.77	7520	4888	1990	213	260	1876	940	1.14	345	274	1000	18.8	18.5	0.02
HSD - 33	7.25	978	636	373	202	246	87	130	0.73	81	42	62	4	8.4	0.00
HSD - 35	7.25	947	616	350	210	256	86	125	1.27	68	44	67	6.5	3.1	0.05
HSD - 38	7.39	1631	1060	574	236	287	229	225	1.04	115	70	130	6.5	5.7	0.00
HSD - 39	6.98	1059	688	417	215	262	95	150	0.88	81	52	60	5.5	11.0	0.00
HSD - 4	7.23	1826	1187	524	194	236	296	245	1.18	94	70	152	9.6	16.7	0.02
HSD - 40	7.03	2190	1424	614	176	215	381	300	0.59	117	78	210	13	14.5	0.34
HSD - 41	6.82	1675	1089	612	269	327	195	275	1.24	128	71	140	7.9	14.5	0.05
HSD - 42	7.09	6440	4186	2090	213	260	1623	800	1.08	423	251	653	20	8.4	0.01
HSD - 46	7.4	980	637	381	201	244	92	133	0.91	87	40	58	7.8	2.6	0.01
HSD - 48	7.06	1806	1174	630	217	264	297	230	0.99	130	74	150	8.8	8.4	0.02
HSD - 5	7.15	2620	1703	919	197	240	493	300	1.05	180	114	190	11.8	24.6	0.01
HSD - 6	7.05	1496	972	490	248	302	183	225	1.12	75	74	147	9.8	6.6	0
HSD - 7	7.14	4790	3114	1460	255	310	926	817	1.25	240	209	546	13	9.7	0.04
HSD - 8	7.17	1170	761	415	208	254	128	165	0.88	78	53	92	7	9.7	0.01
HSD - 9	6.88	892	580	336	207	252	86	95	0.77	72	38	58	7.2	4.0	0.09
HSD -18	7.73	570	370	245	142	173	55	80	0.76	49	30	40	3.5	4.4	0.01
HSD -20	7.12	999	649	376	208	253	98	120	1.11	85	40	60	9.3	6.2	0.02
HSD 201	7.43	1724	1121	481	177	216	294	225	0.00	74	72	162	9.6	15.4	0.03
HSD 202	7.36	7660	4979	2004	218	265	1890	1060	1.47	315	296	1012	24	20.2	0.03
HSD 203	7.61	5910	3842	2082	241	294	1212	1080	1.22	342	298	616	17	60.3	0.01
HSD 204	7.87	1419	922	514	189	230	194	190	0.78	103	62	101	6.9	19.8	0.22

Sample ID	pH	EC µS/cm	Concentration, mg/l												
			TDS	TH	TA	HCO_3	Cl	SO_4	F	Ca	Mg	Na	K	NO_3	Fe
HSD 205	7.66	1081	703	487	302	369	110	115	0.52	91	63	69	5.4	8.8	0.03
HSD 206	6.6	4170	2711	1244	263	321	871	570	0.91	223	167	450	18.2	8.8	0.01
HSD 207	7.06	8950	5818	2674	221	269	2205	1475	0.99	391	412	1100	47	33.9	0.09
HSD 208	6.88	23200	15080	4924	152	185	5870	2166	1.80	622	819	3100	80	1.3	5.44
HSD 209	7.04	6440	4186	1745	306	373	1406	1160	1.38	238	280	950	24.25	18.9	0.01
HSD -21	7.17	1434	932	543	212	258	163	240	1.05	112	64	96	9.9	3.5	0.00
HSD 211	7.5	5050	3283	1372	284	346	1089	780	1.1	208	207	700	17.6	13.2	0.01
HSD 215	6.85	5000	3250	1406	268	326	1105	630	1.1	272	176	600	12.4	19.8	0.02
HSD 217	6.78	5150	3348	1769	256	312	1283	530	1.1	341	223	490	15.8	10.6	0.02
HSD -24	7.33	1232	801	368	229	279	135	135	0.54	49	60	94	8.5	5.3	0.80
HSD -27	8.28	2380	1547	767	206	251	389	410	0.86	131	107	233	7.9	38.3	0
HSD -28	8.11	3630	2360	1068	252	307	724	590	0.9	198	139	460	7	30.8	0.03
HSD -30	6.97	1842	1197	529	194	237	285	260	0.95	84	78	150	7.6	28.6	0.01
HSD -32	6.94	3670	2386	1065	192	233	745	510	1.14	172	154	348	16.4	24.6	0.04
HSD -34	7.69	713	463	284	169	205	53	95	1.03	53	37	40	3.7	3.5	0.02
HSD -36	7.06	2520	1638	750	206	251	410	360	1.01	136	99	238	8.4	32.2	0.03
HSD -37	7.19	1513	983	446	184	225	215	205	0.93	67	68	105	6.9	21.6	0.15
HSD -43	7.57	901	586	354	214	260	71	110	0.61	73	42	55	5	8.4	0.09
HSD -44	7.4	981	638	379	207	253	88	130	0.65	84	41	62	6.2	10.1	0.07
HSD -45	7.38	772	502	329	195	238	75	83	0.54	78	32	40	7.3	2.6	0.64
HSD -47	6.86	1050	683	441	332	404	87	120	1.30	87	55	70	4.3	7.5	0.00
HSD212	6.64	7120	4628	2202	286	348	1780	940	1.28	379	305	900	16.2	16.3	0.09
HSD213	6.84	6550	4258	1774	301	367	1438	1120	1.51	275	264	950	23	15.8	0.05
HSD214	6.69	8530	5545	2967	248	303	2306	1040	1.29	538	394	960	15.4	16.7	0.02
HSD216	6.73	11220	7293	3265	305	372	3144	1600	1.46	452	519	1512	29	13.2	0.09
HSU - 2	7.09	3480	2262	796	225	275	602	530	1.15	112	126	479	6.3	63.8	0.02
HSU -10	7	1067	694	422	227	277	114	110	1.54	91	47	67	7	28.2	0.08
HSU -11	7.07	5590	3634	1500	200	244	1163	867	1.2	264	204	703	18.2	27.3	0.03
HSU- 13	7.18	840	546	346	239	291	58	90	1.45	75	39	44	4.8	4.5	0.09
HSU- 14	7.37	842	547	337	236	288	61	90	1.3	68	41	49	5.2	2.6	0.06
HSU- 15	8.02	3550	2308	1045	204	249	641	600	0.86	180	145	380	9.2	24.2	0.04
HSU- 16	8.29	2240	1456	731	180	220	353	460	0.78	135	96	228	7	44.0	0.03
HSU- 17	8.14	2420	1573	794	200	243	382	390	0.9	158	97	219	8.7	51.9	0.02
HSU- 19	6.88	3260	2119	976	210	255	568	490	0.87	179	128	315	11.4	52.8	0.00
HSU 200	6.91	8330	5415	1757	223	272	1837	1320	1.55	213	297	1330	25	72.2	0.1
HSU 201	6.94	1530	995	423	181	221	240	200	0.98	85	51	120	8.9	12.8	0.1
HSU 203	758	492.7	350	254	309	0	85	1	71	42	55	5	1.32	0.1	NA
HSU 204	7.06	2520	1638	842	414	505	256	470	0.66	141	119	250	12.4	36.1	0.03
HSU 205	7.11	821	534	343	284	347	55	65	0.51	71	40	50	5.8	9.7	0.00

Sample ID	pH	EC µS/cm	Concentration, mg/l												
			TDS	TH	TA	HCO_3	Cl	SO_4	F	Ca	Mg	Na	K	NO_3	Fe
HSU -29	6.46	4010	2607	1037	222	271	791	490	1.22	165	152	450	14.8	25.1	0.02
HSU -30	7.02	932	606	346	242	295	73	100	0.91	64	45	69	5.7	8.4	0.04
HSU -31	6.72	1945	1264	674	232	283	316	270	1.17	148	74	166	8.4	5.7	0.01
HSU -35	7.00	1312	853	466	263	321	141	150	0.98	89	59	105	5.8	21.1	0.01
HSU -36	6.92	7020	4563	1749	245	299	1791	680	1.21	308	238	900	16.8	33.4	0.02
HSU -42	7.03	2570	1671	729	245	299	425	320	1.01	117	106	257	6.8	16.3	0.00
HSU -47	7.02	2690	1749	742	250	305	468	300	0.84	138	96	285	8.2	32.1	0.00
HSU -48	7.31	1012	658	373	194	236	105	120	0.81	68	49	66	5.3	20.7	0.02
HSU- 49	7.25	1063	691	400	224	273	91	125	1.12	81	48	67	6.6	24.6	0.00
HSU- 5	6.89	5710	3712	1490	248	302	1379	560	1.04	243	215	710	13	28.2	0.07
HSU -50	7.61	839	545	372	228	278	66	110	1.23	55	57	55	5.3	27.3	0.00
HSU -51	7.24	866	563	354	271	330	59	65	1.01	62	48	53	5	14.5	0.00
HSU -52	7.05	2300	1495	703	233	284	385	300	0.89	135	89	225	8.1	19.4	0.01
HSU -53	7.12	3350	2178	809	228	277	519	560	1.17	127	119	394	9.1	22.9	0.05
HSU -54	6.95	4580	2977	1309	228	277	969	600	1.23	227	180	500	13.4	25.1	0.15
HSU -56	7.06	3100	2015	841	241	294	585	400	1.22	153	111	368	9.2	22.0	0.01
HSU -57	7.58	1545	1004	529	230	280	171	270	1.97	79	80	111	7.8	1.3	0.02
HSU -6	6.80	5120	3328	1095	378	460	1089	460	0.97	170	163	682	19.8	65.6	0.01
HSU- 7	7.00	2200	1430	641	236	288	294	340	1.34	117	85	225	8.9	34.8	0.03
HSU-12	7.03	3970	2581	1093	236	287	808	520	1.66	174	160	410	15	29.5	0.03
HSU-18	6.78	2830	1840	890	183	224	460	550	0.95	174	111	297	9.4	26.4	0
HSU-20	6.44	6100	3965	1702	220	268	1321	920	1.22	291	237	760	18.6	36.5	0.02
HSU-202	6.77	1729	1124	632	268	326	210	300	0.94	125	78	144	7.8	12.3	0.00
HSU-21	6.90	6900	4485	1918	228	277	1580	980	1.35	321	271	873	26	36.1	0.12
HSU-22	7.08	3320	2158	943	221	269	617	440	1.01	173	124	336	13.8	23.8	0.03
HSU-23	6.69	1609	1046	582	189	230	209	250	1.09	104	78	113	6.2	23.3	0.01
HSU-24	6.71	5510	3582	1772	194	237	1272	650	1.29	321	236	546	11.4	81.0	0.03
HSU-26	6.57	1931	1255	663	250	305	304	260	0.92	134	80	176	7.3	15.0	0.00
HSU-27	6.71	1906	1239	654	247	301	267	290	1.06	129	81	164	8	18.9	0.00
HSU-3	6.97	4720	3068	1241	222	270	790	883	1.18	234	159	598	14.8	108.2	0.02
HSU-32	6.70	3830	2490	942	244	297	844	400	0.96	180	120	490	10	30.4	0.00
HSU-33	6.91	1274	828	440	271	330	145	125	0.84	92	51	109	4.5	23.8	0.01
HSU-34	6.99	1480	962	526	255	311	172	195	0.91	101	66	120	5.6	23.3	0.02
HSU-37	7.31	1498	974	536	193	235	198	220	0.89	93	74	115	6	27.7	0.01
HSU-38	6.62	1847	1201	685	280	341	199	330	1.00	133	86	146	9	16.7	0.03
HSU-41	7	3250	2113	1040	236	288	632	390	0.98	207	127	297	10	16.3	0.06
HSU-43	7.16	1399	909	524	245	299	162	185	0.84	106	63	101	5.8	17.2	0.01
HSU-44	7.65	1189	773	453	242	295	118	165	0.95	75	64	82	5.1	1.8	0.00

Sample ID	pH	EC µS/cm	Concentration, mg/l												
			TDS	TH	TA	HCO_3	Cl	SO_4	F	Ca	Mg	Na	K	NO_3	Fe
HSU-46	6.91	3040	1976	880	248	303	547	380	1.03	136	131	300	8.7	43.1	0.06
HSU-57	6.91	1159	753	458	267	325	108	150	0.80	79	63	80	6.2	4.0	0.01
HSU-58	7.09	820	533	339	289	353	52	66	0.55	68	41	50	5.2	11.4	0.04
HSU-61	8.2	1069	695	418	239	291	106	175	1.18	53	69	70	7.5	2.2	0.01
HSU-8	6.89	4970	3231	1586	214	261	683	1220	0.95	307	199	506	12.4	8.4	0.05
HSU-9	7.06	1122	729	430	247	301	105	150	0.84	98	45	77	6.3	4.0	0.06

TDS = Total dissolved solids, mg/l

TH = Total hardness, mg/l

TA = Total alkalinity, mg/l

ANNEX 5:

Alluvial aquifer: Changes in groundwater salinity and composition between 2001 and 2011

No.	Sample ID		Year	EC,	Concentration, mg/l										
	2001	2011		µS/cm	TDS	Ca	Mg	Na	K	HCO_3	Cl	SO_4	NO_3	Fe	F
			2001	1420	1045	94	64	118	11	348	188	204	18	0.05	0.87
1	**D001**	**HSD - 41**	2011	1675	1089	128	71	140	7.9	327	195	275	14.5	0.05	1.24
			2001	4470	2940	303	189	440	22	293	1108	575	10	0.00	0.90
2	**D256**	**HSD - 42**	2011	6440	4186	423	251	653	20	260	1623	800	8.4	0.01	1.08
			2001	9410	6287	489	423	1170	40	281	2439	1434	10	0.29	0.82
3	**D479**	**HSD - 23**	2011	9020	5863	450	428	1045	42	291	2276	1220	8.8	0.05	1.47
			2001	2000	1389	84	103	200	16	354	320	262	49	0.25	0.63
4	**U175**	**HSU-41**	2011	3250	2113	207	127	297	10	288	632	390	16.3	0.06	0.98
			2001	7260	5282	353	336	1020	30	366	2224	925	27	0.00	0.88
5	**U-294**	**HSU-21**	2011	6900	4485	321	271	873	26	277	1580	980	36.1	0.12	1.35
			2001	1480	1090	120	48	150	11	372	167	211	10	0.20	0.22
6	**U423**	**HSU-9**	2011	1122	729	98	45	77	6.3	301	105	150	4.0	0.06	0.84

ANNEX 6:

Conglomerate aquifer: Changes in groundwater salinity and composition between 2001 and 2011

No.	Sample ID		Year	EC,	Concentration, mg/l										
	2001	2011		µS/cm	TDS	Ca	Mg	Na	K	HCO_3	Cl	SO_4	NO_3	Fe	F
			2001	3530	2575	216	151	377	22	354	791	655	8	0.15	0.60
1	D1062	HSD - 7	2011	4790	3114	240	209	546	13	310	926	817	9.7	0.04	1.25
			2001	900	686	77	38	58	14	299	92	101	4	0.78	0.86
2	D1227	HSD - 11	2011	975	634	85	36	64	8.9	259	95	115	2.2	0.03	0.62
			2001	1010	714	92	35	58	13	256	115	143	0	0.20	0.89
3	D248	HSD - 15	2011	1242	807	98	55	70	11.8	207	112	275	5.7	0.05	1.23
			2001	1660	1076	106	73	140	7	271	269	179	29	0.10	0.57
4	D311	HSD - 29	2011	2170	1411	154	82	160	8	234	336	315	22.4	0.00	0.90
			2001	2070	1401	138	85	160	7	271	342	360	36	0.25	0.00
5	D317	HSD -30	2011	1842	1197	84	78	150	7.6	237	285	260	28.6	0.01	0.95
			2001	1300	881	116	46	96	15	290	170	147	0	0.54	0.69
6	D458	HSD - 22	2011	1465	952	68	64	106	9.6	261	183	225	8.4	0.00	0.94
			2001	1540	1102	92	73	140	14	293	214	262	13	0.05	0.93
7	D469	HSD -21	2011	1434	932	112	64	96	9.9	258	163	240	3.5	0.00	1.05
			2001	1420	993	96	68	110	17	314	203	179	4	0.05	0.81
8	D627	HSD - 10	2011	1897	1233	112	83	174	14.8	254	295	285	5.3	0.04	0.81
			2001	3530	2543	192	154	460	27	268	792	614	34	0.09	0.79
9	D978	HSD -32	2011	3670	2386	172	154	348	16.4	233	745	510	24.6	0.04	1.14
			2001	4430	3113	216	168	540	22	390	1334	415	26	0.05	0.15
10	U432	HSU -11	2011	5590	3634	264	204	703	18.2	244	1163	867	27.3	0.03	1.2
			2001	4070	2693	180	161	480	22	317	862	643	26	0.59	0.83
11	U523	HSU-12	2011	3970	2581	174	160	410	15	287	808	520	29.5	0.03	1.66
			2001	6160	4630	305	284	800	28	427	1730	1028	27	0.05	0.85
12	U540	HSU-20	2011	6100	3965	291	237	760	18.6	268	1321	920	36.5	0.02	1.22
			2001	3450	2382	232	154	380	17	250	650	651	47	0.00	0.75
13	U552	HSU-18	2011	2830	1840	174	111	297	9.4	224	460	550	26.4	0	0.95
			2001	3380	2218	208	142	260	17	268	639	638	45	0.00	0.67
14	U554	HSU- 19	2011	3260	2119	179	128	315	11.4	255	568	490	52.8	0.00	0.87
			2001	3830	2741	204	163	490	19	329	771	713	50	0.59	0.77
15	U606	HSU- 15	2011	3550	2308	180	145	380	9.2	249	641	600	24.2	0.04	0.86
			2001	4580	3018	240	279	398	23	268	1280	468	60	0.34	0.80
16	U804	HSU-24	2011	5510	3582	321	236	546	11.4	237	1272	650	81.0	0.03	1.29
			2001	5960	3662	479	174	555	23	439	1326	627	37	0.29	0.76
17	UA-330	HSU -6	2011	5120	3328	170	163	682	19.8	460	1089	460	65.6	0.01	0.97

ANNEX 7:

Sandstone aquifer: Changes in groundwater salinity and composition between 2001 and 2011

No.	Sample ID		Year	EC,	Concentration, mg/l										
	2001	2011		μS/cm	TDS	Ca	Mg	Na	K	HCO_3	Cl	SO_4	NO_3	Fe	F
1	D1001	HSD - 39	2001	960	712	79	46	62	12	299	76	125	11	0.25	0.51
			2011	1059	688	81	52	60	5.5	262	95	150	11.0	0.00	0.88
2	D1031	HSD - 8	2001	1170	919	72	65	99	14	317	85	193	74	0.05	0.36
			2011	1170	761	78	53	92	7	254	128	165	9.7	0.01	0.88
3	D1076	HSD - 6	2001	1170	910	64	59	121	16	326	135	181	6	0.25	0.67
			2011	1496	972	75	74	147	9.8	302	183	225	6.6	0	1.12
4	D1127	HSD -45	2001	860	622	82	41	29	7	287	87	79	9	0.20	0.67
			2011	772	502	78	32	40	7.3	238	75	83	2.6	0.64	0.54
5	D1133	HSD - 46	2001	760	538	80	32	24	7	281	76	34	1	1.57	0.44
			2011	980	637	87	40	58	7.8	244	92	133	2.6	0.01	0.91
6	D1215	HSD - 12	2001	800	607	60	39	44	8	329	55	63	7	0.10	1.03
			2011	842	547	62	42	53	6.2	257	70	90	7.4	0.01	0.98
7	D230	HSD - 48	2001	1540	1048	122	60	130	12	299	261	160	3	0.05	0.92
			2011	1806	1174	130	74	150	8.8	264	297	230	8.4	0.02	0.99
8	D245	HSD - 38	2001	1600	1139	118	70	160	8	320	259	191	13	0.00	0.64
			2011	1631	1060	115	70	130	6.5	287	229	225	5.7	0.00	1.04
9	D268	HSD - 40	2001	1050	682	78	47	34	9	253	128	111	22	0.20	0.55
			2011	2190	1424	117	78	210	13	215	381	300	14.5	0.34	0.59
10	D275	HSD - 31	2001	7620	4550	337	274	960	18	244	1950	745	21	0.25	0.68
			2011	7520	4888	345	274	1000	19	260	1876	940	18.5	0.02	1.14
11	D358	HSD - 25	2001	4450	2973	134	251	500	19	302	970	764	32	0.15	0.84
			2011	4770	3101	266	199	550	13	252	967	840	36.5	0.01	0.91
12	D391	HSD -27	2001	2210	1540	128	94	260	11	278	429	311	28	0.15	0.62
			2011	2380	1547	131	107	233	7.9	251	389	410	38.3	0	0.86
13	D406	HSD -28	2001	3730	2528	162	191	440	15	271	950	467	30	0.15	0.81
			2011	3630	2360	198	139	460	7	307	724	590	30.8	0.03	0.9
14	D467	HSD -24	2001	980	669	76	36	58	13	293	109	81	1	0.64	0.86
			2011	1232	801	49	60	94	8.5	279	135	135	5.3	0.80	0.54
15	D474	HSD -20	2001	1000	722	102	35	59	16	287	96	123	4	0.25	0.78
			2011	999	649	85	40	60	9.3	253	98	120	6.2	0.02	1.11
16	D510	HSD - 16	2001	640	433	58	28	20	12	238	59	15	0	2.06	0.61
			2011	712	463	76	22	39	8.1	212	69	70	2.2	0.06	0.77
17	D521	HSD - 5	2001	2890	1785	196	148	200	19	250	653	292	25	0.25	0.84
			2011	2620	1703	180	114	190	12	240	493	300	24.6	0.01	1.05
18	D523	HSD - 4	2001	1820	1157	136	75	123	16	262	309	221	14	0.20	0.92
			2011	1826	1187	94	70	152	9.6	236	296	245	16.7	0.02	1.18
19	D560	HSD - 2	2001	940	657	86	32	59	15	256	120	87	2	0.05	0.83
			2011	984	640	70	45	60	9.6	236	117	100	27.3	0.03	1.11
20	D565	HSD - 1	2001	1670	1114	122	61	142	13	281	295	175	23	0.00	0.83
			2011	1420	923	97	61	117	7.7	250	195	195	12.3	0.03	1.16

No.	Sample ID		Year	EC,	Concentration, mg/l										
	2001	2011		μS/cm	TDS	Ca	Mg	Na	K	HCO_3	Cl	SO_4	NO_3	Fe	F
			2001	1020	779	76	60	70	12	293	122	125	19	0.20	0.84
21	D566	HSD - 3	2011	1186	771	79	61	79	7.6	261	139	165	12.3	0.01	1.19
			2001	850	555	34	54	45	11	278	80	49	4	0.25	1.04
22	D602	HSD - 9	2011	892	580	72	38	58	7.2	252	86	95	4.0	0.09	0.77
			2001	950	707	82	35	74	16	271	127	100	2	0.00	0.68
23	D636	HSD - 17	2011	1171	761	83	45	96	12.4	222	152	155	2.2	0	0.95
			2001	2290	1576	158	70	260	13	244	443	336	50	1.47	0.64
24	D660	HSD - 19	2011	2140	1391	92	81	189	8	231	339	300	29.0	0.04	0.87
			2001	1290	1024	92	41	140	10	256	243	216	24	0.10	0.59
25	D771	HSD -37	2011	1513	983	67	68	105	6.9	225	215	205	21.6	0.15	0.93
			2001	870	726	72	29	80	9	311	101	99	24	0.00	0.53
26	D778	HSD -44	2011	981	638	84	41	62	6.2	253	88	130	10.1	0.07	0.65
			2001	850	687	76	26	80	9	299	83	102	10	0.00	0.48
27	D785	HSD -43	2011	901	586	73	42	55	5	260	71	110	8.4	0.09	0.61
			2001	1310	892	72	43	140	17	281	125	213	0	0.44	0.83
28	D863	HSD - 35	2011	947	616	68	44	67	6.5	256	86	125	3.1	0.05	1.27
			2001	820	647	68	31	80	9	275	80	91	13	0.20	0.55
29	D960	HSD - 33	2011	978	636	81	42	62	4	246	87	130	8.4	0.00	0.73
			2001	1770	1196	140	67	150	15	311	278	223	11	0.25	0.66
30	U007	HSU -31	2011	1945	1264	148	74	166	8.4	283	316	270	5.7	0.01	1.17
			2001	2210	1466	127	74	184	16	348	319	259	137	0.69	0.84
31	U1017	HSU -56	2011	3100	2015	153	111	368	9.2	294	585	400	22.0	0.01	1.22
			2001	2550	1579	147	62	255	18	311	447	312	24	0.49	0.78
32	U1046	HSU -52	2011	2300	1495	135	89	225	8.1	284	385	300	19.4	0.01	0.89
			2001	1230	877	91	41	96	13	366	110	139	20	0.00	0.75
33	U1113	HSU-43	2011	1399	909	106	63	101	5.8	299	162	185	17.2	0.01	0.84
			2001	1300	910	65	61	123	14	342	124	160	20	0.00	0.67
34	U1200	HSU-34	2011	1480	962	101	66	120	5.6	311	172	195	23.3	0.02	0.91
			2001	1310	1082	91	48	123	13	360	110	106	230	0.15	0.62
35	U1210	HSU-33	2011	1274	828	92	51	109	4.5	330	145	125	23.8	0.01	0.84
			2001	1360	929	83	50	120	14	329	160	155	18	0.29	0.69
36	U1293	HSU- 5	2011	5710	3712	243	215	710	13	302	1379	560	28.2	0.07	1.04
			2001	1060	743	88	31	67	13	314	115	109	3	0.44	0.60
37	U1317	HSU -10	2011	1067	694	91	47	67	7	277	114	110	28.2	0.08	1.54
			2001	830	577	68	31	48	10	302	46	69	3	0.10	0.81
38	U1346	HSU- 14	2011	842	547	68	41	49	5.2	288	61	90	2.6	0.06	1.3
			2001	1980	1431	132	111	150	21	336	208	460	11	0.69	0.67
39	U167	HSU-38	2011	1847	1201	133	86	146	9	341	199	330	16.7	0.03	1.00
			2001	1450	1028	124	62	104	13	329	184	208	2	0.29	0.63
40	U207	HSU-44	2011	1189	773	75	64	82	5.1	295	118	165	1.8	0.00	0.95

No.	Sample ID		Year	EC,	Concentration, mg/l										
	2001	2011		μS/cm	TDS	Ca	Mg	Na	K	HCO_3	Cl	SO_4	NO_3	Fe	F
			2001	1730	1163	130	66	150	13	323	257	200	22	0.34	0.65
41	U-466	HSU-26	2011	1931	1255	134	80	176	7.3	305	304	260	15.0	0.00	0.92
			2001	2950	2057	184	115	320	18	299	566	528	25	0.39	0.68
42	U-531	HSU-22	2011	3320	2158	173	124	336	13.8	269	617	440	23.8	0.03	1.01
			2001	2270	1767	176	106	260	16	262	452	451	43	0.20	0.67
43	U558	HSU- 17	2011	2420	1573	158	97	219	8.7	243	382	390	51.9	0.02	0.9
			2001	2350	1543	160	84	240	14	250	410	342	42	0.00	0.64
44	U605	HSU- 16	2011	2240	1456	135	96	228	7	220	353	460	44.0	0.03	0.78
			2001	2410	1598	80	99	300	13	354	431	296	25	0.10	0.67
45	U730	HSU -42	2011	2570	1671	117	106	257	6.8	299	425	320	16.3	0.00	1.01
			2001	1480	946	88	67	105	23	275	199	158	32	0.15	0.71
46	U861	HSU-37	2011	1498	974	93	74	115	6	235	198	220	27.7	0.01	0.89
			2001	3300	2121	165	111	366	21	323	688	430	15	0.34	0.81
47	U940	HSU -54	2011	4580	2977	227	180	500	13.4	277	969	600	25.1	0.15	1.23
			2001	2300	1459	94	78	225	16	384	408	239	14	0.39	0.67
48	U946	HSU-32	2011	3830	2490	180	120	490	10	297	844	400	30.4	0.00	0.96
			2001	1110	842	82	50	90	12	366	78	122	40	0.39	0.88
49	UA-135	HSU-58	2011	820	533	68	41	50	5.2	353	52	66	11.4	0.04	0.55
			2001	930	674	43	52	75	14	311	53	109	16	0.20	0.86
50	UA-167	HSU -30	2011	932	606	64	45	69	5.7	295	73	100	8.4	0.04	0.91
			2001	810	582	41	53	42	12	323	32	61	17	0.29	0.86
51	UA-221	HSU -51	2011	866	563	62	48	53	5	330	59	65	14.5	0.00	1.01
			2001	1490	977	75	42	138	14	329	152	209	15	0.25	0.76
52	UA-337	HSU- 7	2011	2200	1430	117	85	225	8.9	288	294	340	34.8	0.03	1.34
			2001	990	753	48	58	83	13	366	53	102	29	0.44	0.86
53	UA-380	HSU -50	2011	839	545	55	57	55	5.3	278	66	110	27.3	0.00	1.23

ANNEX 8:

Water suitability for irrigation (salinity and sodium hazards)

Sample ID	EC µS/cm	Ca, mg/l	Ca, meq/l	Mg, mg/l	Mg, meq/l	Na, mg/l	Na, meq/l	SAR
HSD 210	5110	216	10.8	203	16.7	679	29.5	8.0
HSD - 1	1420	97	4.8	61	5.0	117	5.1	2.3
HSD - 10	1897	112	5.6	83	6.9	174	7.6	3.0
HSD - 11	975	85	4.2	36	3.0	64	2.8	1.5
HSD - 12	842	62	3.1	42	3.4	53	2.3	1.3
HSD - 13	973	79	3.9	45	3.7	59	2.6	1.3
HSD - 14	3100	208	10.4	107	8.8	312	13.6	4.4
HSD - 16	712	76	3.8	22	1.8	39	1.7	1.0
HSD - 17	1171	83	4.1	45	3.7	96	4.2	2.1
HSD - 19	2140	92	4.6	81	6.7	189	8.2	3.5
HSD - 2	984	70	3.5	45	3.7	60	2.6	1.4
HSD - 22	1465	68	3.4	64	5.3	106	4.6	2.2
HSD - 23	9020	450	22.5	428	35.2	1045	45.5	8.5
HSD - 25	4770	266	13.3	199	16.3	550	23.9	6.2
HSD - 29	2170	154	7.7	82	6.7	160	7.0	2.6
HSD - 3	1186	79	4.0	61	5.0	79	3.4	1.6
HSD - 31	7520	345	17.2	274	22.5	1000	43.5	9.8
HSD - 33	978	81	4.0	42	3.4	62	2.7	1.4
HSD - 35	947	68	3.4	44	3.6	67	2.9	1.6
HSD - 38	1631	115	5.7	70	5.7	130	5.7	2.4
HSD - 39	1059	81	4.1	52	4.3	60	2.6	1.3
HSD - 4	1826	94	4.7	70	5.8	152	6.6	2.9
HSD - 40	2190	117	5.8	78	6.4	210	9.1	3.7
HSD - 41	1675	128	6.4	71	5.9	140	6.1	2.5
HSD - 42	6440	423	21.1	251	20.6	653	28.4	6.2
HSD - 48	1806	130	6.5	74	6.1	150	6.5	2.6
HSD - 5	2620	180	9.0	114	9.4	190	8.3	2.7
HSD - 6	1496	75	3.7	74	6.1	147	6.4	2.9
HSD - 7	4790	240	12.0	209	17.2	546	23.8	6.2
HSD - 8	1170	78	3.9	53	4.4	92	4.0	2.0
HSD - 9	892	72	3.6	38	3.1	58	2.5	1.4
HSD -18	570	49	2.4	30	2.5	40	1.7	1.1
HSD -20	999	85	4.2	40	3.3	60	2.6	1.3
HSD 201	1724	74	3.7	72	5.9	162	7.0	3.2
HSD 202	7660	315	15.7	296	24.3	1012	44.0	9.8
HSD 203	5910	342	17.1	298	24.5	616	26.8	5.9
HSD 204	1419	103	5.2	62	5.1	101	4.4	1.9
HSD 206	4170	223	11.1	167	13.7	450	19.6	5.6
HSD 207	8950	391	19.5	412	33.9	1100	47.9	9.3
HSD 209	6440	238	11.9	280	23.0	950	41.3	9.9

Sample ID	EC µS/cm	Ca, mg/l	Ca, meq/l	Mg, mg/l	Mg, meq/l	Na, mg/l	Na, meq/l	SAR
HSD -21	1434	112	5.6	64	5.2	96	4.2	1.8
HSD 211	5050	208	10.4	207	17.0	700	30.5	8.2
HSD 215	5000	272	13.6	176	14.5	600	26.1	7.0
HSD 217	5150	341	17.0	223	18.3	490	21.3	5.1
HSD -24	1232	49	2.4	60	4.9	94	4.1	2.1
HSD -27	2380	131	6.5	107	8.8	233	10.1	3.7
HSD -28	3630	198	9.9	139	11.4	460	20.0	6.1
HSD -30	1842	84	4.2	78	6.4	150	6.5	2.8
HSD -32	3670	172	8.6	154	12.7	348	15.1	4.6
HSD -34	713	53	2.6	37	3.0	40	1.7	1.0
HSD -36	2520	136	6.8	99	8.2	238	10.3	3.8
HSD -37	1513	67	3.3	68	5.6	105	4.5	2.2
HSD -47	1050	87	4.3	55	4.5	70	3.0	1.5
HSD212	7120	379	18.9	305	25.1	900	39.2	8.3
HSD213	6550	275	13.7	264	21.7	950	41.3	9.8
HSD214	8530	538	26.9	394	32.4	960	41.8	7.7
HSD216	11220	452	22.6	519	42.6	1512	65.8	11.5
HSU - 2	3480	112	5.6	126	10.3	479	20.9	7.4
HSU -10	1067	91	4.5	47	3.9	67	2.9	1.4
HSU -11	5590	264	13.2	204	16.8	703	30.6	7.9
HSU- 13	840	75	3.7	39	3.2	44	1.9	1.0
HSU- 15	3550	180	9.0	145	11.9	380	16.5	5.1
HSU- 16	2240	135	6.7	96	7.9	228	9.9	3.7
HSU- 17	2420	158	7.9	97	8.0	219	9.5	3.4
HSU- 19	3260	179	8.9	128	10.6	315	13.7	4.4
HSU 204	2520	141	7.0	119	9.8	250	10.9	3.8
HSU 205	821	71	3.6	40	3.3	50	2.2	1.2
HSU -29	4010	165	8.2	152	12.5	450	19.6	6.1
HSU -30	932	64	3.2	45	3.7	69	3.0	1.6
HSU -31	1945	148	7.4	74	6.1	166	7.2	2.8
HSU -35	1312	89	4.4	59	4.9	105	4.6	2.1
HSU -36	7020	308	15.4	238	19.6	900	39.2	9.4
HSU -42	2570	117	5.9	106	8.7	257	11.2	4.2
HSU -48	1012	68	3.4	49	4.0	66	2.9	1.5
HSU- 49	1063	81	4.0	48	4.0	67	2.9	1.4
HSU- 5	5710	243	12.1	215	17.6	710	30.9	8.0
HSU -52	2300	135	6.7	89	7.3	225	9.8	3.7
HSU -53	3350	127	6.3	119	9.8	394	17.1	6.0
HSU -54	4580	227	11.3	180	14.8	500	21.7	6.0
HSU -56	3100	153	7.7	111	9.1	368	16.0	5.5

Sample ID	EC µS/cm	Ca, mg/l	Ca, meq/l	Mg, mg/l	Mg, meq/l	Na, mg/l	Na, meq/l	SAR
HSU- 7	2200	117	5.8	85	7.0	225	9.8	3.9
HSU-12	3970	174	8.7	160	13.2	410	17.8	5.4
HSU-18	2830	174	8.7	111	9.1	297	12.9	4.3
HSU-20	6100	291	14.5	237	19.5	760	33.1	8.0
HSU-202	1729	125	6.2	78	6.4	144	6.3	2.5
HSU-21	6900	321	16.0	271	22.3	873	38.0	8.7
HSU-22	3320	173	8.6	124	10.2	336	14.6	4.8
HSU-23	1609	104	5.2	78	6.4	113	4.9	2.0
HSU-24	5510	321	16.0	236	19.4	546	23.8	5.6
HSU-26	1931	134	6.7	80	6.5	176	7.7	3.0
HSU-27	1906	129	6.4	81	6.6	164	7.1	2.8
HSU-3	4720	234	11.7	159	13.1	598	26.0	7.4
HSU-32	3830	180	9.0	120	9.8	490	21.3	6.9
HSU-33	1274	92	4.6	51	4.2	109	4.8	2.3
HSU-34	1480	101	5.1	66	5.5	120	5.2	2.3
HSU-37	1498	93	4.6	74	6.1	115	5.0	2.2
HSU-38	1847	133	6.6	86	7.1	146	6.4	2.4
HSU-41	3250	207	10.3	127	10.4	297	12.9	4.0
HSU-43	1399	106	5.3	63	5.2	101	4.4	1.9
HSU-44	1189	75	3.8	64	5.3	82	3.5	1.7
HSU-57	1159	79	3.9	63	5.2	80	3.5	1.6
HSU-58	820	68	3.4	41	3.4	50	2.2	1.2
HSU-61	1069	53	2.6	69	5.7	70	3.0	1.5
HSU-8	4970	307	15.3	199	16.3	506	22.0	5.5
HSU-9	1122	98	4.9	45	3.7	77	3.3	1.6

Very high salinity hazard (EC > 2250 µS/cm) is highlighted in red

High salinity hazard (750< EC <2250 µS/cm)) is highlighted in orange

Medium sodium hazard (10<SAR<18) is highlighted in red

Sodium Adsorption Ratio (SAR) is calculated from formula:

$$SAR = \frac{Na}{\sqrt{0.5}(Ca + Mg)}$$

Where the concentrations of cations are in meq/l