هيئة البيئة - أبوظبي
Environment Agency - ABU DHABI

Groundwater Quality Baseline Survey

Summary Report Published 2019

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Abbreviations

δ	Delta
λ	Decay constant
‰	per mille
a_0	Initial activity
a_t	Activity after time t
b.d.l.	below detection limit
BP	Before Present
BOD	Biological Oxygen Demand
Bq	Becquerel
CBE	Charge Balance Error
CFC	Chlorofluorocarbon
CFU	Colony Forming Units
COD	Chemical Oxygen Demand
CRM	Certified Reference Material
DIC	Dissolved Inorganic Carbon
DOC	Dissolved Organic Carbon
EC	Electrical Conductivity
ka	Kilo years (1 000 years)
R	isotope ratio
SAR	Sodium Adsorption Ratio
SF_6	Sulphur Hexafluoride
TDS	Total Dissolved Solids
TOC	Total Organic Carbon
Tot.	Total
VOC	Volatile Organic Compound
BTEX	benzene, toluene, ethylbenzene and xylene
TSE	Treated sewage effluent
meq-%	milliequivalent
µS/cm	micro Siemens per centimetre
CT	Computed tomography
As	Arsenic
B	Boron
Ba	Barium
Cr (tot)	total chromium
Cr (VI) (Cr6+)	hexavalent chromium
Fe	Iron
Li	Lithium
Mo	Molybdenum
Ni	Nickel
Se	Selenium
Sr	Strontium
U	Uranium
V	Vanadium
C^{12}	Carbon-12
C^{13}	Carbon-13
^{14}N	Nitrogen-14
^{15}N	Nitrogen-15
^{2}H	Hydrogen-2 (Deuterium)
^{3}H	Hydrogen-3 (Tritium)
^{18}O	Oxygen-18
Ra-226	Radium-226
Ra-228	Radium-228
^{87}Sr	Strontium-87 Isotope
^{86}Sr	Strontium-86 Isotope
N_2	Nitrogen
O_2	Oxygen
CH_4	Methane
4,4'-DDD	Dichlorodiphenyldi-chloroethane
AIR	atmospheric air
QA/QC	quality assurance/ quality control

Executive summary

Environment Agency - Abu Dhabi (EAD) optimised a groundwater monitoring programme between 2014 - 2016. The Groundwater Monitoring Programme monitors changes in groundwater quantity (levels) and quality. The groundwater quality baseline was set in 2018 through the Groundwater Quality Baseline Survey project (GWQBS). This report aims to provide a summary outlining the approaches and main findings of the GWQBS project.

The project collected groundwater samples using a monitoring grid of 39 cells in Abu Dhabi and Al Ain Regions and 60 cells in the Al Dhafra region. These samples were then analysed in an international accredited laboratory using a predefined schedule of hydrochemical parameters.

As a first step, suitable sampling wells were identified using criteria such as the proximity to different types of landuse along with corresponding groups of quality parameters that should be analysed at the laboratory. The predefined quality parameters include: major ions, trace metals, nutrients, fuel compounds, wastewater indicators, microbiology, pesticides, radioactive radiations, as well as the environmental isotopes that help in assessing the origin and age of groundwater. Planning for groundwater baseline sampling started in November 2017, followed by the sampling operations that took place from January 2018 until April 2018.

Chemical and isotopic findings suggest that the bulk of groundwater is fossil or at least pre-modern, apart from the Eastern region along the border with Oman, where groundwater replenishment occurs. Due to the often long residence times, most waters were naturally found to be relatively salty. As a result, several other water constituents, such as chromium or boron, were also found in high concentrations. There were several other cases however, where traces of human-induced contaminants were detected, mainly from agricultural activities like pesticide residuals, Nitrates, Phorate, Ronnel, Chlorpyrifos, and Aldrin. Residential contaminants also were evident like Amidotrizoic acid and total coliforms. This finding suggests a modern recharge in some wells that can come from return flow of irrigation water. Water Quality Indices were then calculated based on relevant parameters for selected uses including domestic (non-potable), irrigation purposes, and livestock watering for Camels and Goats in particular.

Although recharge is usually deemed a positive feature in the water management context, it also can mean a certain extent of aquifer vulnerability to contamination. Given this fact, a regular monitoring scheme is suggested in relatively short time intervals.

In addition to this regular monitoring programme, two specific studies are recommended for the future. In order to investigate the origin of groundwater and the high concentrations of natural constituents, the first recommended study, incorporate geochemical data from rock and soil samples to address the source of high levels of trace metals in the study area like Chromium and Boron. The second suggested study is a precipitation monitoring scheme, in which the isotopic and chemical composition of rain is studied. Information on the isotopic fingerprint of precipitation is needed for comparison purposed in groundwater studies. Moreover, data on chloride in rain could be harnessed for recharge estimations via the Chloride Mass Balance method. Trace element concentrations would allow to estimate the atmospheric input into the hydrogeological system.

2014 - 2016

Completed optimising the groundwater monitoring programme

2018

Completed establishing the Groundwater Quality Baseline in Abu Dhabi Emirate

39 & 60

Cells of the monitoring grid in Abu Dhabi and Al Ain Regions

Cells from Al Dhafra region

01

Introduction

The Emirate of Abu Dhabi is located in an extremely arid region receiving an average of 80 mm of rainfall per year. Groundwater is considered one of the major water supply contributors, especially for the agricultural and forestry sectors. However, groundwater recharge in the emirate is not sustainable and therefore, the groundwater sources in Abu Dhabi are prone to stressors. The groundwater reserves have depleted dramatically due to the fact that the amount of groundwater that is extracted far exceeds that which is being naturally recharged.

In Abu Dhabi Emirate, water resources management is facing many challenges especially scarcity of fresh water. Meanwhile, Groundwater contributes majorly to fulfil the demand of three sectors; agriculture, forestry, and amenities, contributing by 93%, 91%, and 31% respectively.

Policies such as food security, which aims to reduce the amount of imported food and achieve 40% local production levels also increase the stress on groundwater resources. With more than 24,000 farms now operating in Abu Dhabi Emirate, the number of plant holdings has increased rapidly in the last four decades, with more than 38 times more than operating in 1971.

By the end of 2016, EAD completed a groundwater monitoring optimisation project in partnership with the United States Geological Survey and developed a groundwater-monitoring programme compromising two monitoring networks, levels and quality. The groundwater quality monitoring network covers extensive areas in the Abu Dhabi Emirate covering the groundwater salinity categorised as directly usable (under 15,000 ppm). Accordingly, EAD started the implementation of this monitoring programme in the year 2017 by launching the (GWQBS) project. This project focused mainly on establishing a groundwater quality baseline and assessing the occurrence of any anthropogenic contaminants. The objectives of the GWQBS project were to: develop a baseline for groundwater quality, assess contamination, and assess natural recharge.

80 mm

Average rainfall per year
because of extremely arid region

More than

24,000

Farms operating
in Abu Dhabi Emirate

02

Design phase of the Groundwater Quality Monitoring Network

2.1 Selection of Groundwater Wells and Sampling Sites

A sampling grid had been introduced earlier, comprising 39 grid cells in Abu Dhabi and Al Ain Regions compared to 60 grid cells in Al Dhafra region. The average cell size is 237 km² and 389 km² respectively. The sampling grid can be seen in Figure 1.

At the beginning, groundwater wells for sampling were selected based on the following criteria:

1. Use Abu Dhabi Habitat Map to assess types of land uses in each cell of the monitoring grid
2. Each grid cell shall have at least one sampling well
3. Sampling wells shall be representative of the dominating landuses
4. Special landuse types shall also be reflected in the selection of sampling wells even if the percentage of these landuse types is small
5. Laboratory analysis shall include basic parameters for all cells, and selected parameters relevant to the type of land use for the developed cells

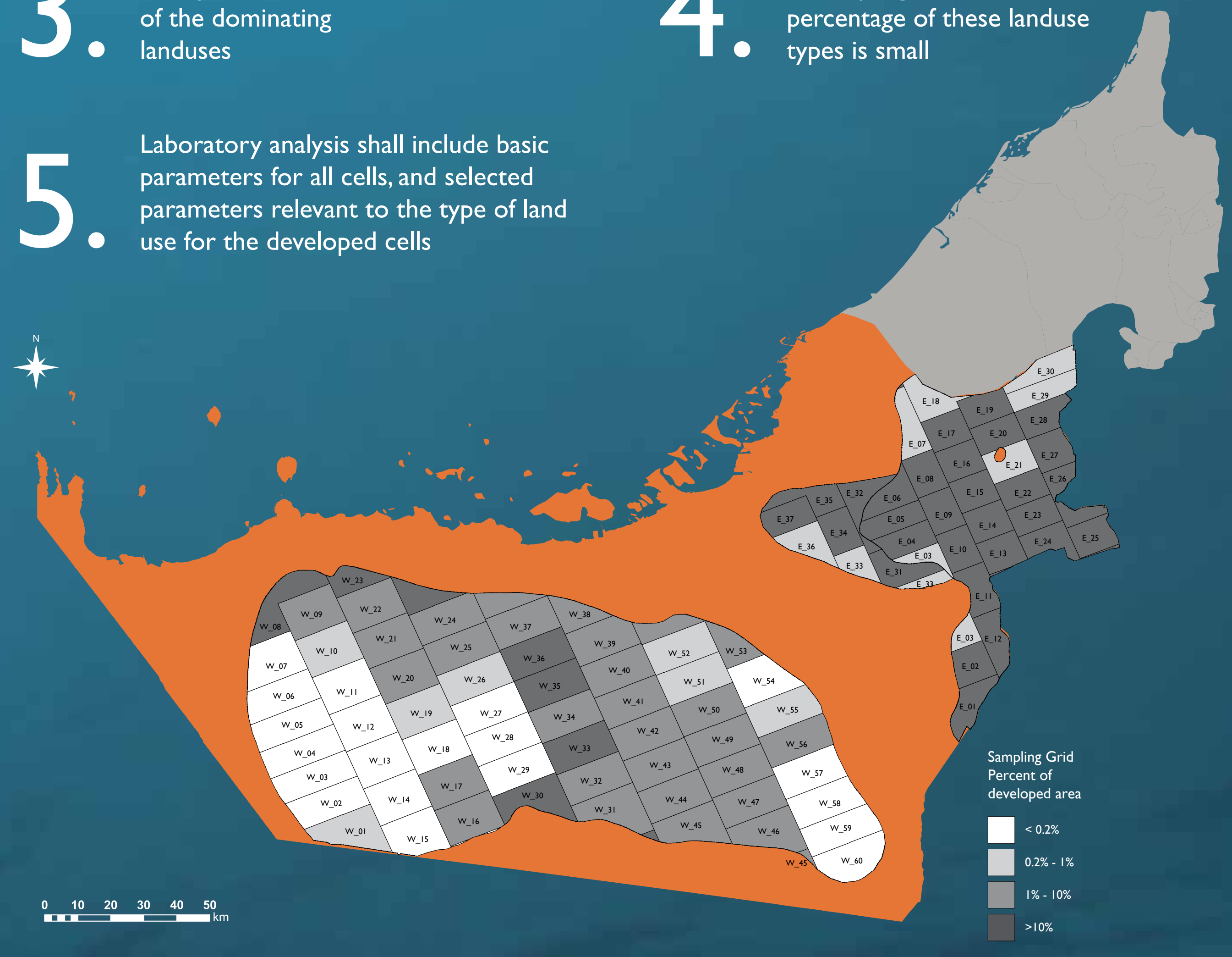

Figure 1: Sampling grid showing percentage of total developed landuse

2.1.1 Classification of Landuse Types

The Abu Dhabi Habitat Map was used to identify the types of landuses. In addition, data from the well inventory project (2016-2018) was used to select the target wells for sampling. The following developed landuse types were considered for the selection of sampling wells:

Types of land uses and their codes	
Code 8100 – Date plantations	Code 9210 – Oil industry
Code 8200 – Farmland	Code 9220 – Airports and aerodromes
Code 8400 – Forestry plantations	Code 9240 – Other industry
Code 8300 – Livestock areas	Code 9400 – Paved roads
Code 9300 – Leisure and landscaped areas	Code 9500 – Pipelines infrastructure
Code 9110 – High density urban areas	Code 9120 – Low density urban areas

For each grid cell, the areas for all the developed landuse types were then calculated using in GIS tools. For each landuse type, the respective area and its percentage coverage of the total grid cell area are given. The allocation of different landuse types in each cell is shown in Figure 2.

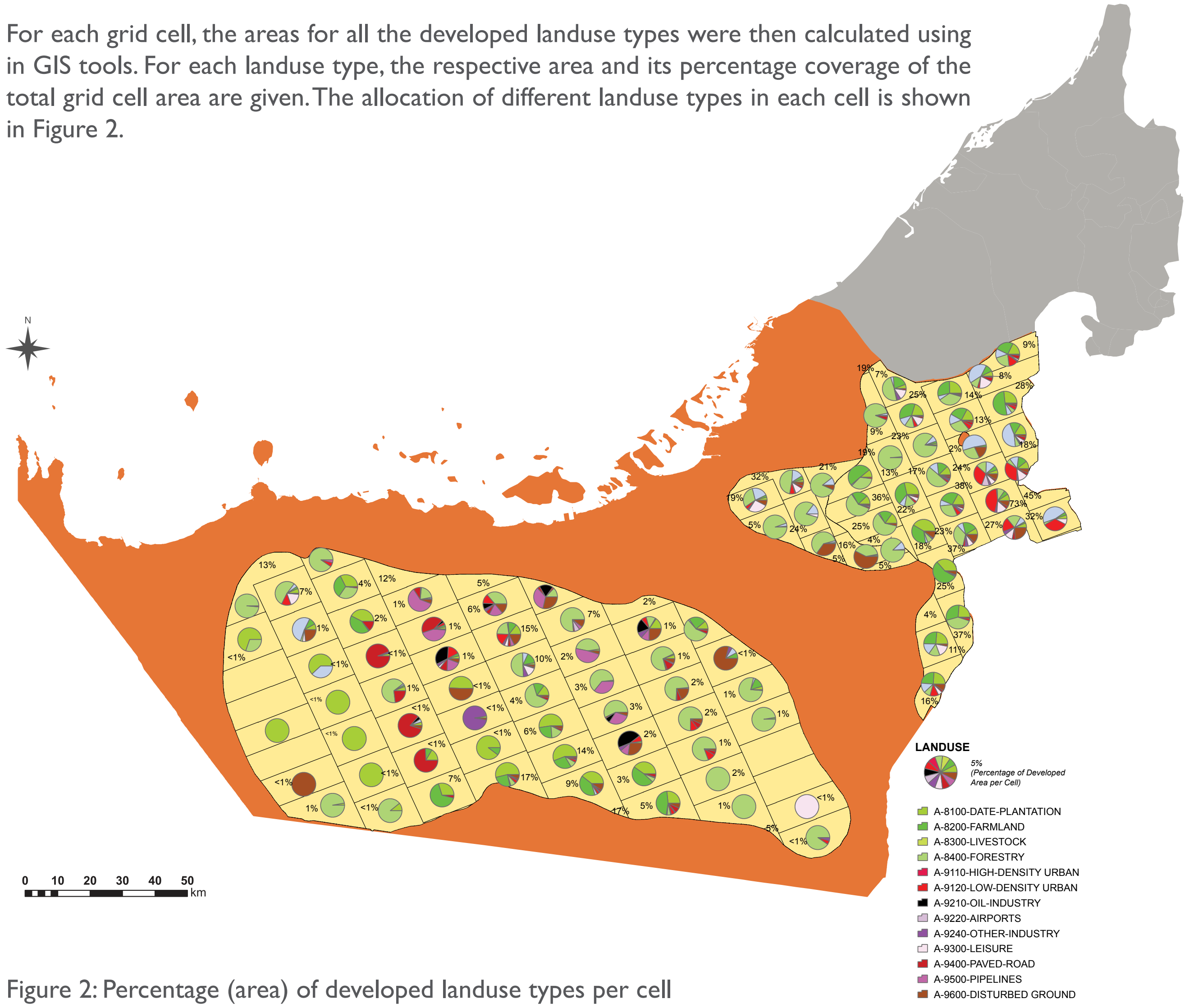

Figure 2: Percentage (area) of developed landuse types per cell

2.1.2 Special Landuse Types

Special landuse locations were included in the sampling programme in order to obtain information on potential groundwater contamination originating from these activities. Most of the locations are concentrated in Al Ain region and along roads.

The special landuse types include are petrol stations, hazmat sites, waste handling sites and landfills, and areas irrigated with TSE.

2.1.3 Selection of Sampling Wells

The initial criteria for identifying target wells for sampling were established in 2016. The allocation process of target wells benefited from the well-inventory project database, comprising data for approximately 118,000 wells, those that were found to be operational, accessible for sampling, and ideally located within a distance of 500 m from the landuse are shown.

Operational wells were preferred for sampling rather than idle ones, because a direct groundwater sample from the aquifer can be obtained compared with Idle wells that require the contained water in the casing to be flushed before collecting the sample.

15

Deep wells were selected for sampling

Aquifer

Groundwater quality monitoring distinguished between shallow and deep aquifers

2.1.4 Deep and Shallow Aquifer

The groundwater-quality monitoring programme distinguished between shallow and deep aquifers in Abu Dhabi. Some deep aquifer wells are not located within or close to the primary or secondary landuse. Nevertheless, these wells were also selected for sampling to provide baseline data on the deep aquifer. Optimally, 15 deep wells were selected for sampling. Figure 3 illustrates the overall selected wells colour indexed as per their respective landuse type.

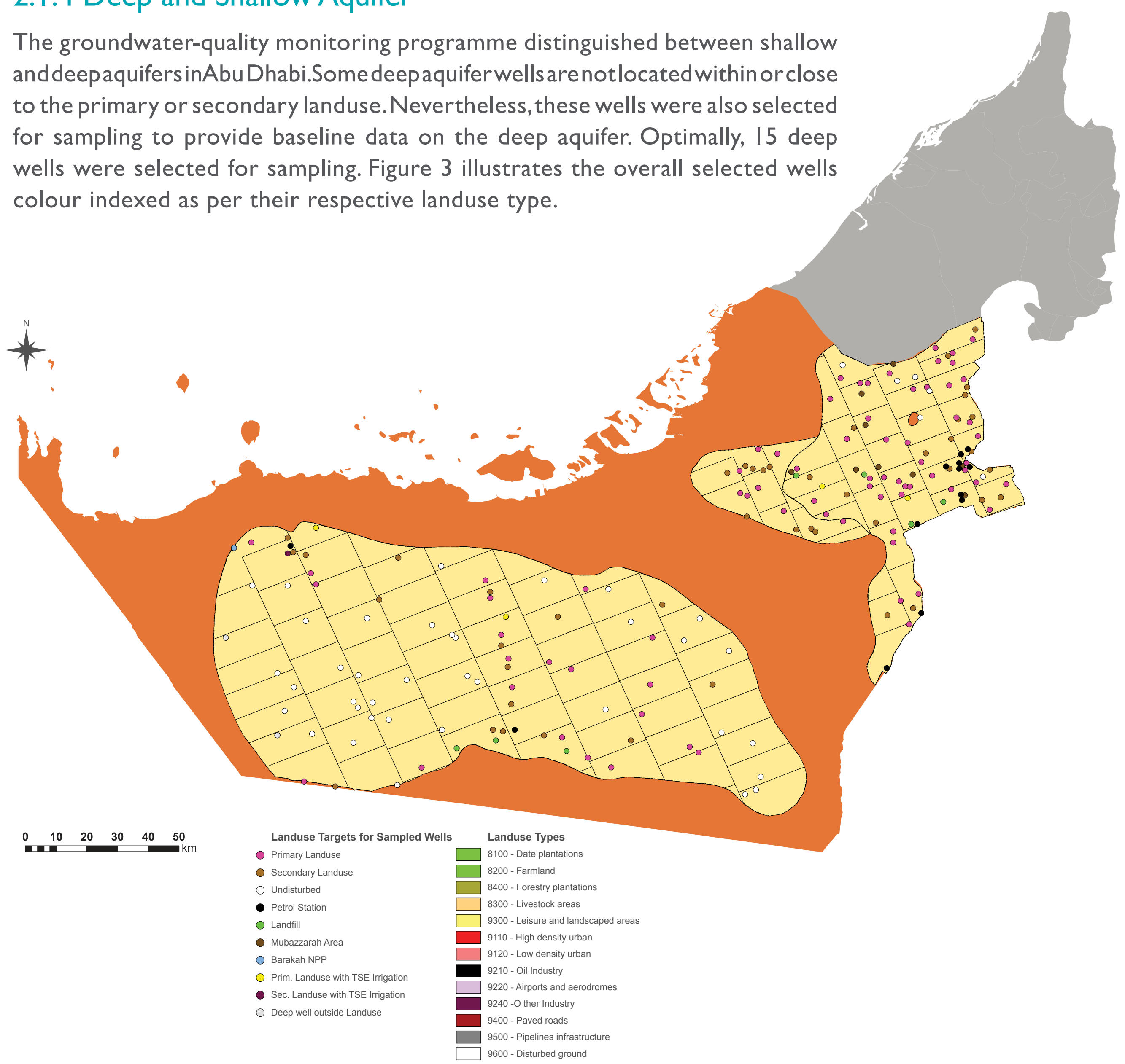

Figure 3: Overall wells selected for sampling

2.2 Selection of Lab Analysis

Following to the well selection for sampling, the lab analysis requirements were identified. Figure 4 illustrates the parameter groups for laboratory analyses beside their respective landuse types. The green cells the right side of the table indicate which parameters were analysed against each landuse type. For example, pesticides were not analysed in samples from undisturbed landuse and petrol stations; VOCs and wastewater indicators were not analysed from undisturbed landuse. However, basic water quality parameters (items No. 8-13, 14) were tested in all samples.

BOQ-3 Item	General Constituent Category	Sampled Constituent(s)
8		Ferrous iron
9	Basic Ions	Major and minor cations
10		Major and minor anions
11		Nutrients (N and P compounds)
12	Trace Metals	Trace elements/metals
13		Chromium (total and VI)
13a	Bacteria	Total coliform, Escherichia (*E . coli*)
13b	Bacteria	Replicate sample Total coliform, Escherichia (*E. coli*)
13c	Bacteria	Field blank Total coliform, Escherichia (*E. coli*)
14	DOC/TOC	Dissolved/total organic carbon
15	Pesticides	Pesticides
16	VOCs	VOCs (BTEX, Tri, Per)
17	Wastewater Reuse	Wastewater indicators
18		Pharmaceutical products
19		N-nitrosodimethyl amine (NDMA)
20	Radio – nuclides	Radium isotopes (Ra-226 & Ra-228)
21		Stable isotopes of water (O18, 2H)
22		Stable isotopes of nitrate (N15)
23		Environmental 87Sr/86 Sr ratio
24	Environmental Analysis	Chlorofluorocarbons (CFC-11, CFC-12, CFC-13) and Sulfur Hexafluoride (SF6)
25	Radioactive Isotopes	Tritium (3H)
26		Carbon-14 isotope (C^{13}/C^{12} ratio)
28		Dissolved atmospheric gases (N_2, O_2, CH_4)

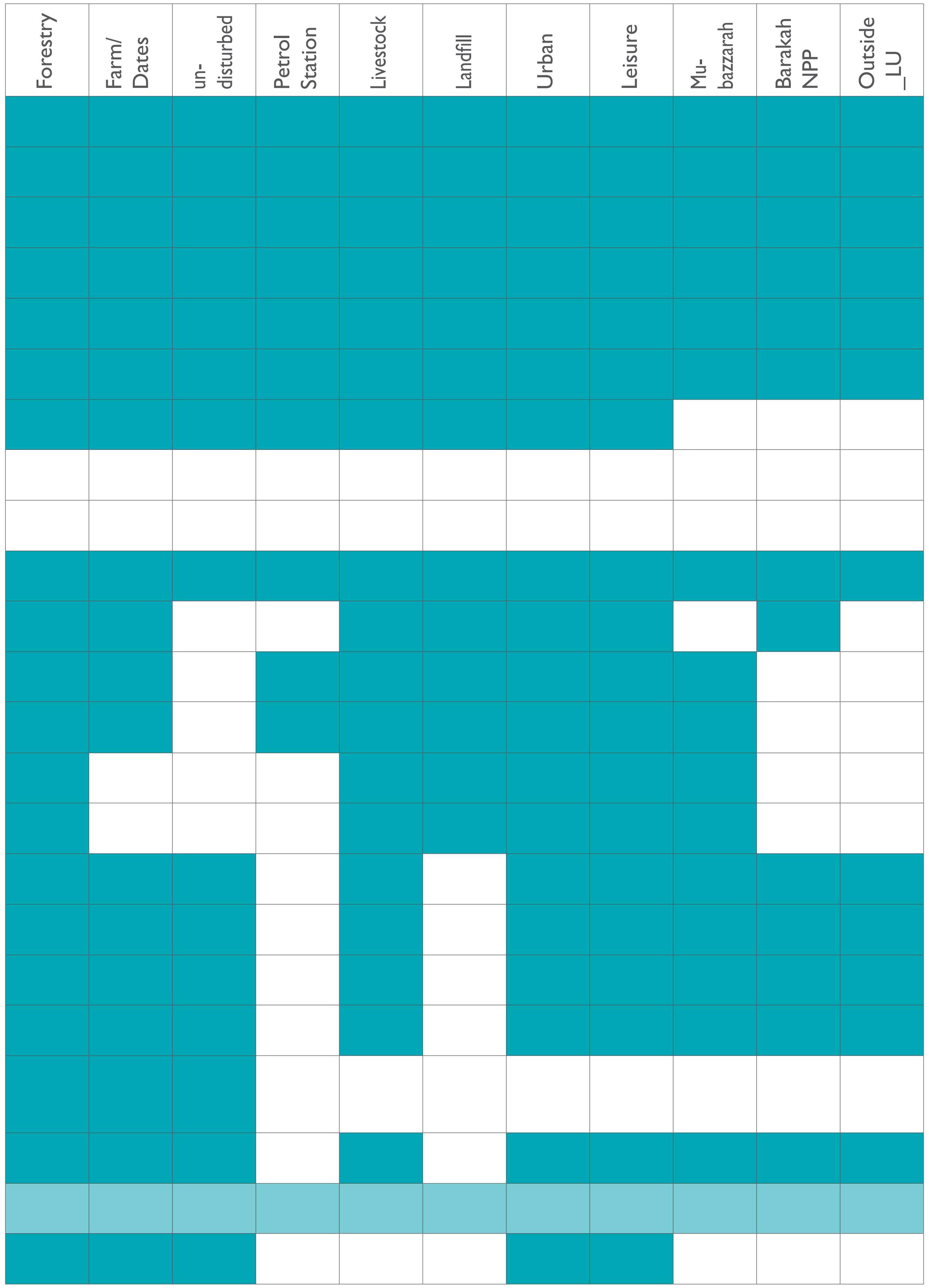

Figure 4: Sampling schedule
(Blue colour indicates parameters to be analysed for respective landuse type)

2.3 Quality Control Sampling

As integral components of this groundwater quality study, Quality-control (QC) samples were sent to the lab along with other samples to determine the acceptability of performance in the data collection process and provide a basis for evaluating the adequacy of procedures used to obtain data, in addition to the internal Lab QC process.

The types of incorporated QC samples were:

1. Replicate sample
2. Field blank
3. Standard reference sample
4. In addition to the internal lab QC methods

A total of 10 % quality control samples were collected and analysed out of the total number of samples collected during this study. According to all above, a groundwater sampling campaign was performed successfully and delivered to the approved lab considering the ideal storage and transportation conditions within the acceptable holding time.

10 %

Quality control samples were collected and analysed out of total

03

Analysis and Interpretation of Lab Results

3.1 General Hydrochemistry

3.1.1 Basic Parameters

As part of this study, a group of parameters such as Electrical Conductivity (EC), pH, and Bicarbonate, were measured at site, right after each groundwater sample was collected. The same parameters were measured and analysed in the lab as well.

Measurements from both methods (site and Lab) have been correlated for validation and demonstrated a linear relation. Some deviations were observed in case of the pH value, which is expected since this value can change after sampling due to temperature changes and degassing. The EC values were further checked in conjunction with the TDS values determined in the laboratory. Since the EC value is a reliable proxy for the total salinity, an excellent correlation was obtained.

Some major ions fractions can differ from sample to sample, thus different water types are classified accordingly. The major ion compositions are visualised in the form of Piper plots (Figure 5). In this type of diagram, the proportions of the major ions are shown in milliequivalent percentages (meq-%). The comparison of the six individual plots reveals subtle differences. While the change in the cations triangle appears to be rather limited, the anion triangles depict a gradual change. With increasing salinity, Chloride gradually becomes the dominant ion, while fresher waters displayed a relatively more even distribution between ions.

Figure 6 displays this concept, while taking into account the spatial distribution of the samples and their relative salinity ranges. Here, small pie charts reflecting the major ion fractions (in meq-%) are shown for selected, representative samples on the salinity map.

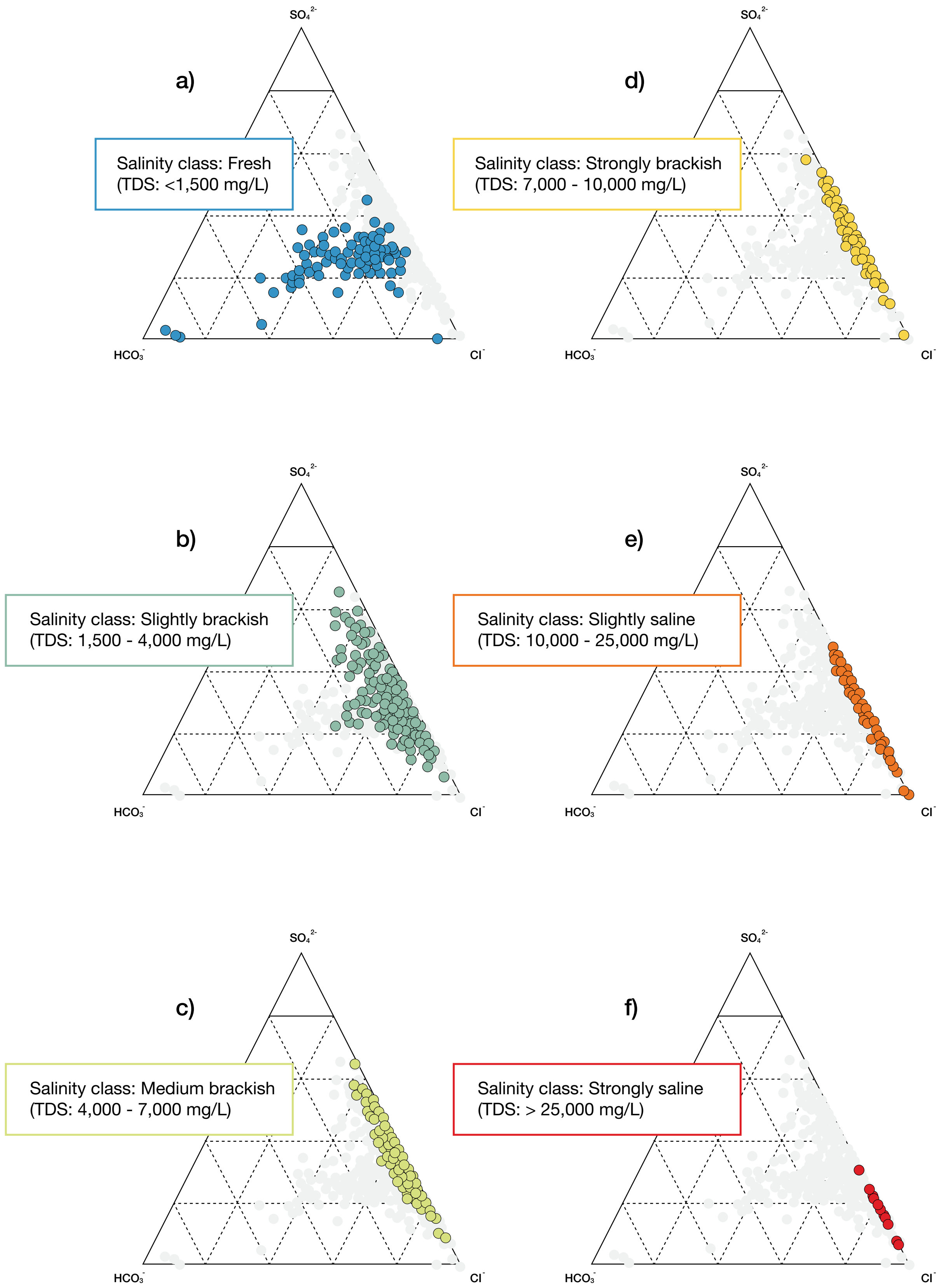

Figure-5: Compilation of anion triangles from the previous Piper plots (all salinity classes).

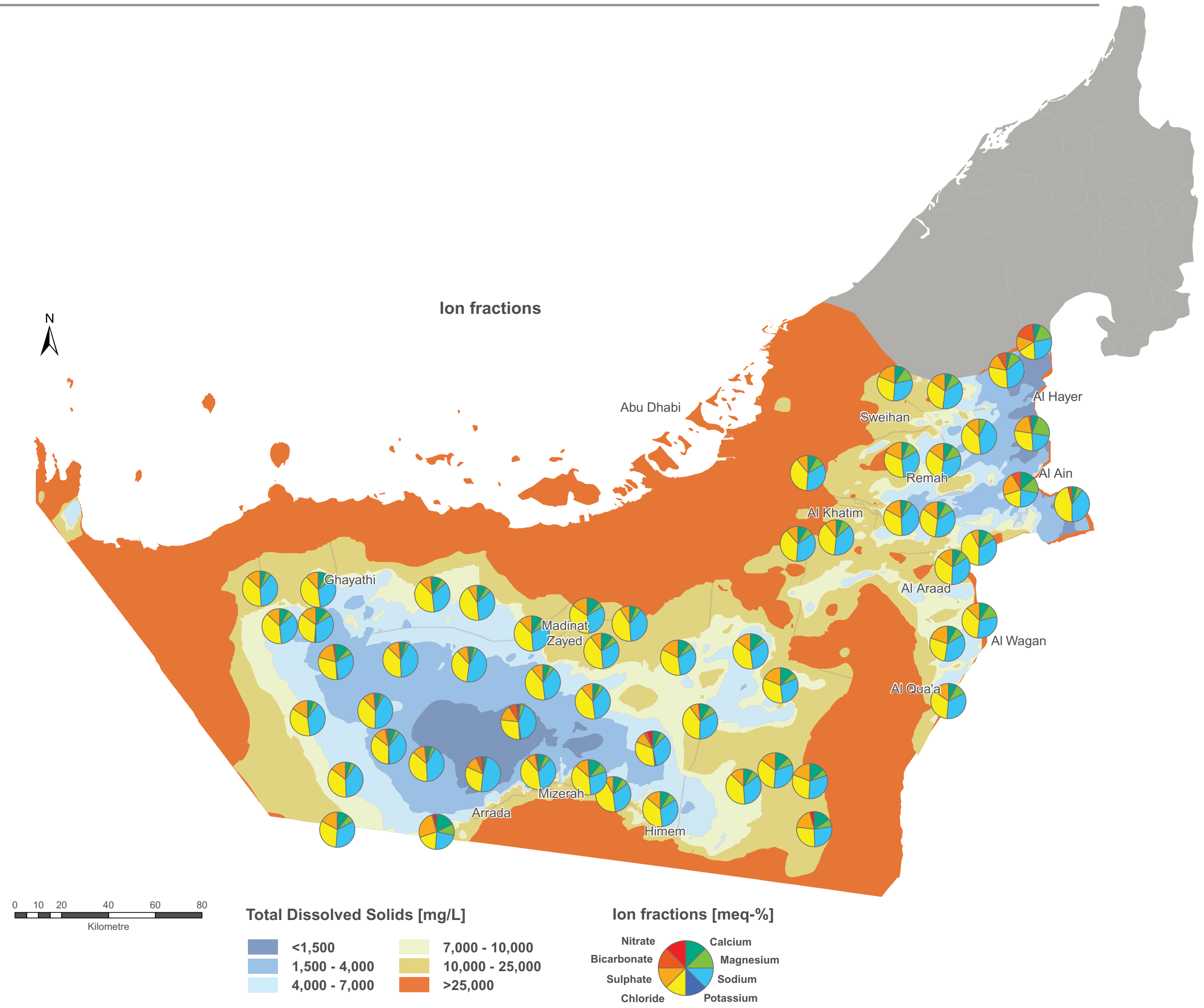

Figure-6: Ion fractions displayed on the groundwater salinity map

While Fluoride and Nitrate do not play an important role in terms of anion fractions, their absolute concentrations are partly substantial. The encountered Fluoride concentrations scatter between values below the detection limit and 7.8 mg/L. Hence, the guideline values for Fluoride for domestic use (0.4 mg/L), irrigation purposes (1 mg/L), and livestock watering (2 mg/L) the concentrations of Fluoride are exceeded in 55, 51, and 39 cases in the present data set, respectively.

In the case of Nitrate, when considering the 2017 EAD guideline value for domestic non-potable use (45 mg/L), 76 guideline violations were observed and even the mean value exceeded the threshold. Figure 7 shows that elevated values occur mainly, but not exclusively in agricultural areas like the Liwa crescent. Elevated Nitrate concentrations are a rather common phenomenon in arid areas, however previous studies find elevated values to be in agricultural regions also, suggesting an influence from fertilisers. To a certain extent, the presence of Nitrate in the groundwater is also related to the abundance of Dissolved Oxygen (usually several mg/L). Under these oxic conditions, Nitrate is rather stable.

1 mg/L

Fluoride guideline values for irrigation use

76

Nitrate guideline violations were observed

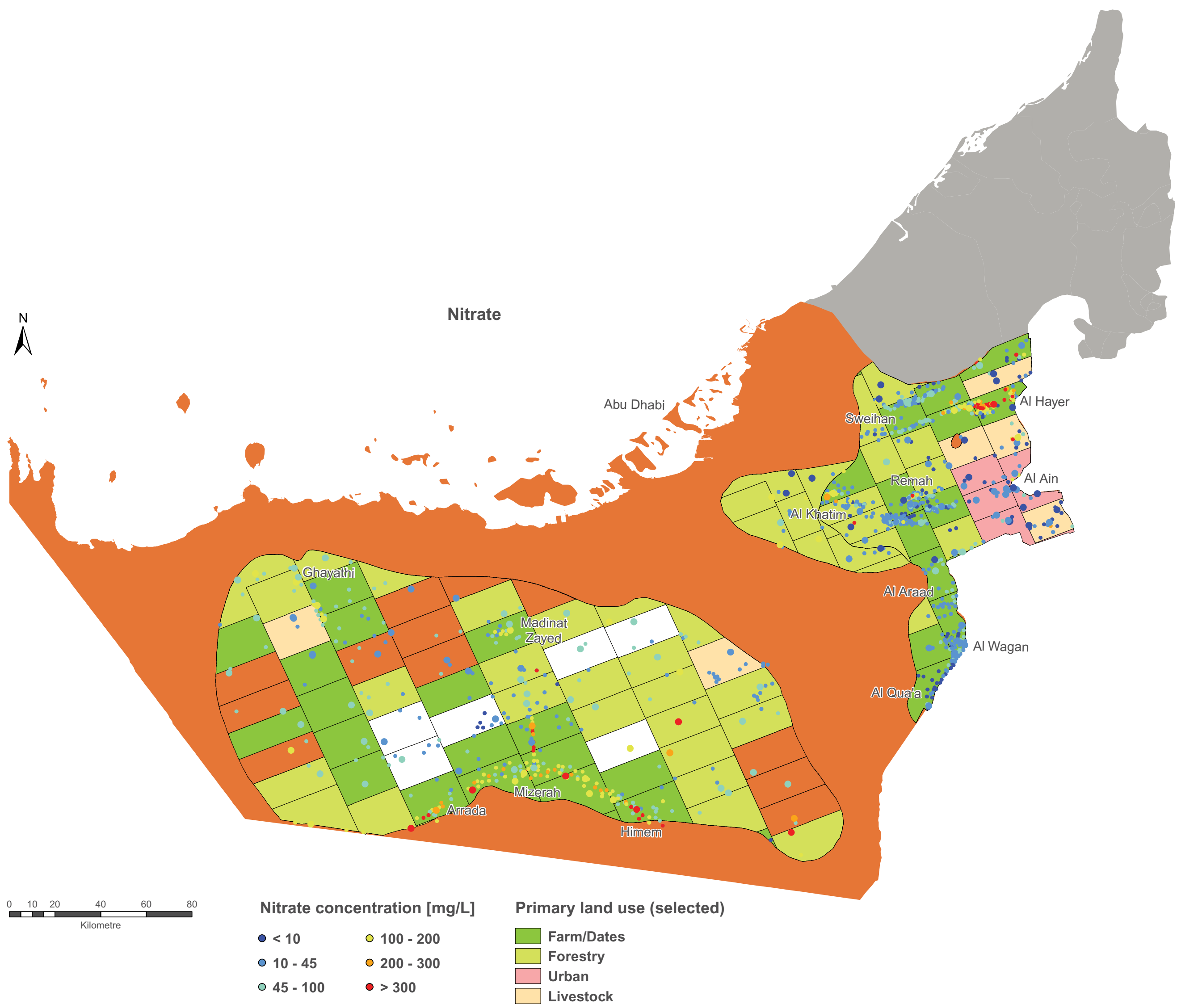

Figure-7: Nitrate concentrations along with their respective landuses

3.1.2 Source of Nitrate (Nitrogen-15)

Since Nitrate seems to be an issue in the study area, an attempt was made to gain further insights into potential sources of nitrate that are dissolved in water by analysing the isotope Nitrogen-15 (15N).

The found δ15N values range between -8.4 and 29.5‰ AIR (mean: 6.4‰ AIR). Despite the significant scatter, most values lie between 0 and 10‰ AIR. The plot does not reveal a correlation between δ15N and the Nitrate concentration and the isotope data are not very conclusive.

To a large extent, this is due to the fact that the isotopic signatures of potential sources show significant overlap. Nevertheless, the bulk of the Nitrate values that exceed 45mg/L are associated with farming or forestry activities. In addition, pesticides were proven in part of the same samples.

While a few of the urban wells exhibit elevated δ15N values, roughly matching with the isotopic signature of septic waste, one has to keep in mind that denitrification, a natural process, also causes an enrichment of the heavier 15N isotope (and a decrease in Nitrate).

While urban areas are apparently characterised by relatively low Nitrate values, numerous elevated concentrations occur in other settings. Hence, it seems that fertilisers used in agricultural settings play a role in the Nitrate context.

3.1.3 Trace Elements

Most of the obtained analysis results for trace elements show a rather large scatter, which is in line with the distinct salinity variations and the presence of a range of water types (see previous section).

In the case of Arsenic, three exceedances of the EAD (2017) guideline value were recorded. The Arsenic distribution is not showing a systematic spatial pattern is not apparent. The fact that Arsenic, but also other trace elements, occasionally appear erratically is attributable to the fact that well depths can differ, but also to the complicated interplay of (hydro) geochemical factors which can tend to influence trace element occurrence.

Boron and Chromium concentrations range found between 296 µg/L and 18,760 µg/L (*i.e.* 18.8 mg/L). These concentrations are clearly elevated and violate some of the guideline values at different landuses. Typically, elevated Boron concentrations are used as an indicator for wastewater, because Perborate commonly occurs as a bleaching agent in detergents. Moreover, fertilisers occasionally contain Boron as a micro-nutrient and occasionally, also desalination units (based on the reverse osmosis principle) have been discussed as a potential Boron source. However, elevated Boron concentrations are apparently a wide-spread phenomenon in the region and also occur in remote areas with limited impact by human activity, such anthropogenic sources can mostly be ruled out as the main cause. Instead, a geogenic source seems to be more likely. Moreover, it is noteworthy that seawater exhibits appreciable Boron contents. Thus, some of the Boron dissolved in groundwater might be derived from sea spray, either through dry deposition or through washout from the atmosphere by rain.

The hypothesis that Boron could be of natural origin is also supported by the following Figure 8, summarising the Boron concentrations (incl. data from the Well Inventory Project) in the form of box plots.

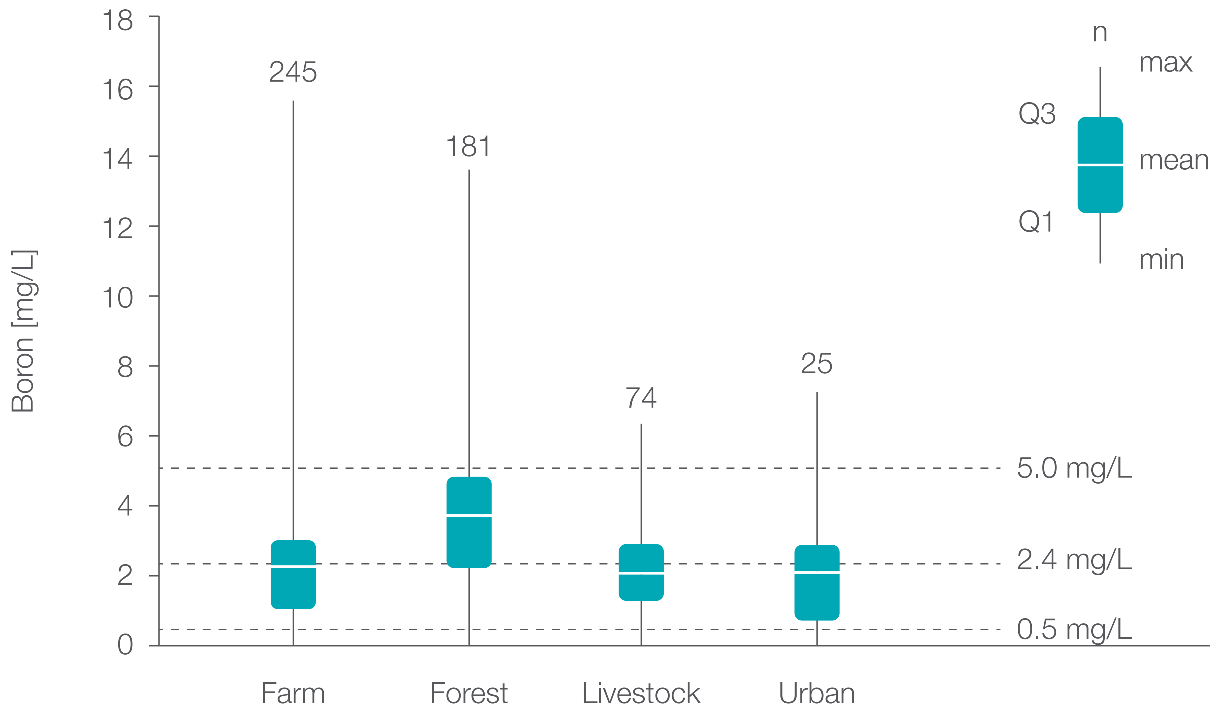

Figure 8: Boron box plots for selected land uses.

In the case of Chromium, the concentrations in the present data set range between values below the detection limit and 569 µg/L. As the threshold defined for domestic, non-potable use is 50 µg/L, numerous concentrations are deemed elevated. This becomes particularly clear in Figure 9, summarising the corresponding data of the present Baseline and the Well Inventory Project.

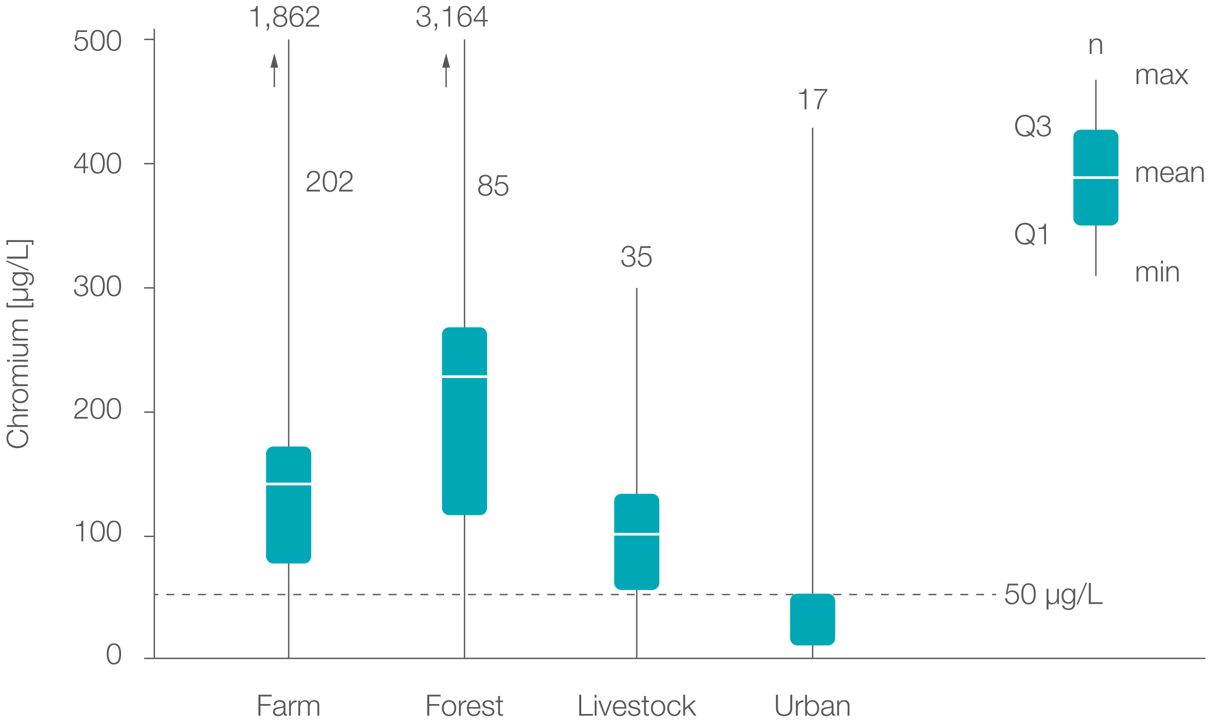

Figure 9: Chromium box plots for selected land uses.

Chromium elevated concentrations is quite common. Although a number of authors have addressed the issue, the underlying mobilisation mechanism is apparently not agreed upon. A common hypothesis related to weathering of olivine and pyroxene with subsequent sorption of Cr6+ on Iron and Manganese oxide coatings; these are abraded, transported by wind, and deposited on the surface, where they can be dissolved by infiltrating rain to reach groundwater.

Where an anthropogenic input through applying fertilisers containing traces of Chromium as a micro-nutrient in proven.

A limited input from sea spray cannot be ruled out. On the basis of the currently available data it is not possible to decide, which of these mechanisms is to be favoured - all of the above-mentioned minerals can be found in UAE sediments.

Furthermore, also Selenium stands out due to appreciable concentrations. The values range between concentrations below the detection limit and 135 µg/L. While these levels also imply guideline value exceedances (e.g. in case of domestic use), one has to consider the salinities of the concerned samples Figure 10.

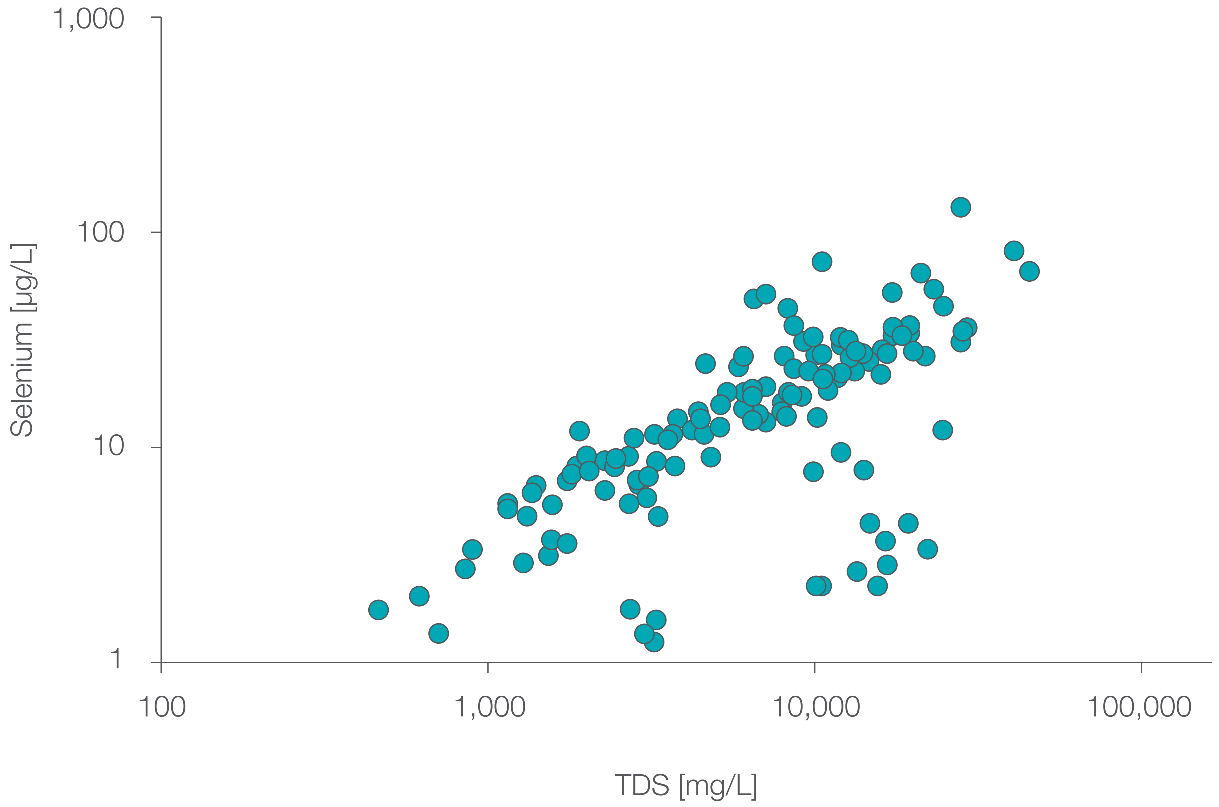

Figure 10: Scatter plot showing the relation between Selenium and total salinity

The scatter plot indicates that elevated Selenium concentrations mainly occur in salty groundwater that can anyway not be used for domestic purposes. While this correlation might suggest an evaporative enrichment of Selenium, it is also possible that the elevated salinities promote trace element mobilisation. Moreover, salty waters feature a multitude of ions with which the trace elements have to compete for sorption sites. Also, this phenomenon would lead to higher trace element concentrations in the groundwater.

In terms of Molybdenum, concentrations range between values below the detection limit and 1,541 µg/L (mean: 52.3 µg/L). As EAD's (2017) guideline value for irrigation and livestock use is somewhat low (10 µg/L), numerous concentrations exceed this threshold. Due to a rather erratic Molybdenum distribution, spatial predictions are difficult, but low values cluster in the east.

A non-systematic distribution is also observed for Nickel. Here, concentrations range from values below the detection limit to 152 µg/L. A few samples showed concentrations above the EAD (2017) guideline value of 20 µg/L defined for domestic use. None of the found concentrations violated the other thresholds for irrigation purposes (200 µg/L) and livestock watering (1,000 µg/L). Finally, a correlation matrix was created for selected trace elements (see Figure 11).

200 µg/L

Nickel guideline value for irrigation and livestock

0 Violations

of Nickel concentrations for irrigation and livestock watering

	As	B	Ba	Cr (tot)	Cr (VI)	Fe	Li	Mo	Ni	Se	Sr	U	V
As	1												
B	0.03	1											
Ba	-0.16	-0.23	1										
Cr (tot)	0.03	0.44	-0.24	1									
Cr (VI)	0.02	0.28	-0.33	0.91	1								
Fe	-0.06	-0.06	-0.04	-0.13	-0.21	1							
Li	0.06	0.78	-0.27	0.34	0.23	-0.06	1						
Mo	0.52	0.30	-0.16	0.11	0.07	-0.05	0.29	1					
Ni	0.54	0.09	-0.04	-0.05	-0.11	0.05	0.15	0.62	1				
Se	-0.06	0.46	-0.12	0.22	0.15	-0.12	0.71	0.09	0.08	1			
Sr	-0.05	0.49	0.07	0.22	0.06	-0.08	0.56	0.11	0.04	0.59	1		
U	0.02	0.39	-0.16	-0.06	-0.11	-0.06	0.40	0.08	0.07	0.12	0.11	1	
V	0.65	0.11	-0.15	0.15	0.10	-0.07	0.10	0.03	0.49	0.01	0.03	0.11	1

Colour legend

-1.0 -0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8 1.0

strong... ...negative correlation weak... weak... ...positive correlation strong...

Figure 11: Correlation matrix for selected trace elements.

Most correlation coefficients are rather low, indicating a very limited potential for source identification in the present case. The only high correlation coefficient – 0.91 – is noted for the combination Total Chromium/Hexavalent Chromium.

3.2 Anthropogenic Assessment

3.2.1 Pesticides

The majority of the tested pesticides were found below the detection limit of 0.002 mg/L. where seven pesticides could be detected (partly in traces only) as illustrated in Figure 12.

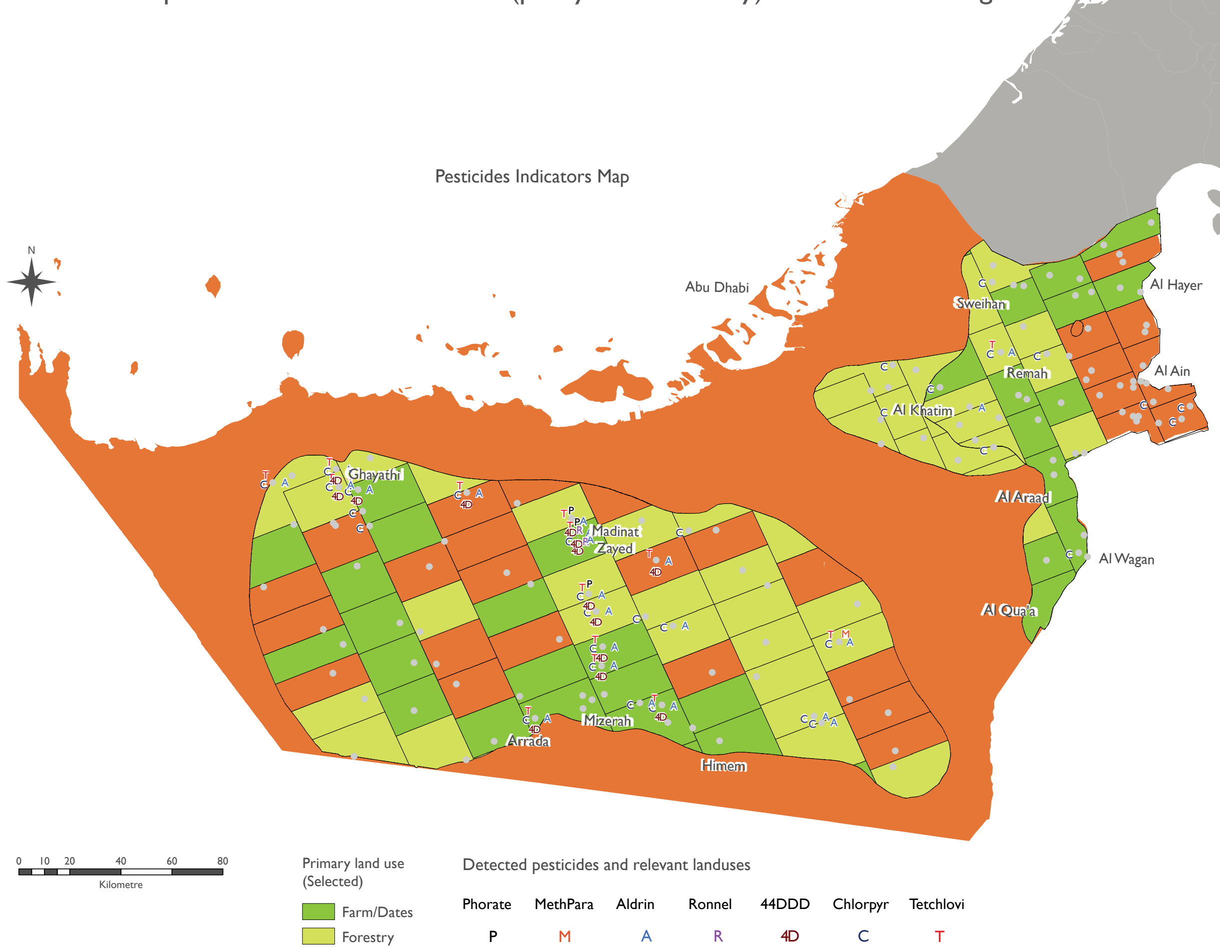

Figure 12: Distribution map of detected pesticides

As expected, most of the concerned wells (in total 37) are forest or farm wells, with the exception of Chlorpyrifos, which was found in urban areas of Al Ain. Only Chlorpyrifos additionally occurred in an urban area (Al Ain area), which is attributable to the fact that this pesticide is not only used as an agrochemical, but is also applied regularly in residential environments.

Most of the found pesticides are primarily insecticides belonging to the Organophosphate group. Aldrin and 4,4'-DDD are exceptions in this regard - they are members of the Organochlorine group. With exception to Chlorpyrifos, the majority of the compounds are considered to have a low leachability. Such information can be retrieved from the Pesticide Properties Database (PPDB; AERU 2018). This database features a number of physico-chemical pesticide properties and derived indices.

In view of these mostly low leachability potentials, it is rather remarkable that these compounds were detected in the gathered samples and that the total number of detects amounts to 37. These findings seem to reflect the intensive use of pesticides in the UAE. Moreover, they possibly indicate preferential flow paths allowing a rapid percolation. Also, sandy soils with low organic carbon contents, implying a limited sorption capacity, might play a role in this context. This finding thus suggests a certain aquifer vulnerability in the study area.

3.2.2 Pharmaceuticals

The pharmaceuticals analyses comprised the following compounds: Carbamazepine, Ibuprofen, Diclofenac, and Amidotrizoic acid. The first three compounds were not found, *i.e.* the determined concentrations were below the detection limit of 10 ng/L. However, Amidotrizoic acid, a contrast agent for medical X-ray examinations and computer tomography (CT) scans, could be detected in five cases (see Figure 13) falling in the range of 24 µg/L to 172 µg/L.

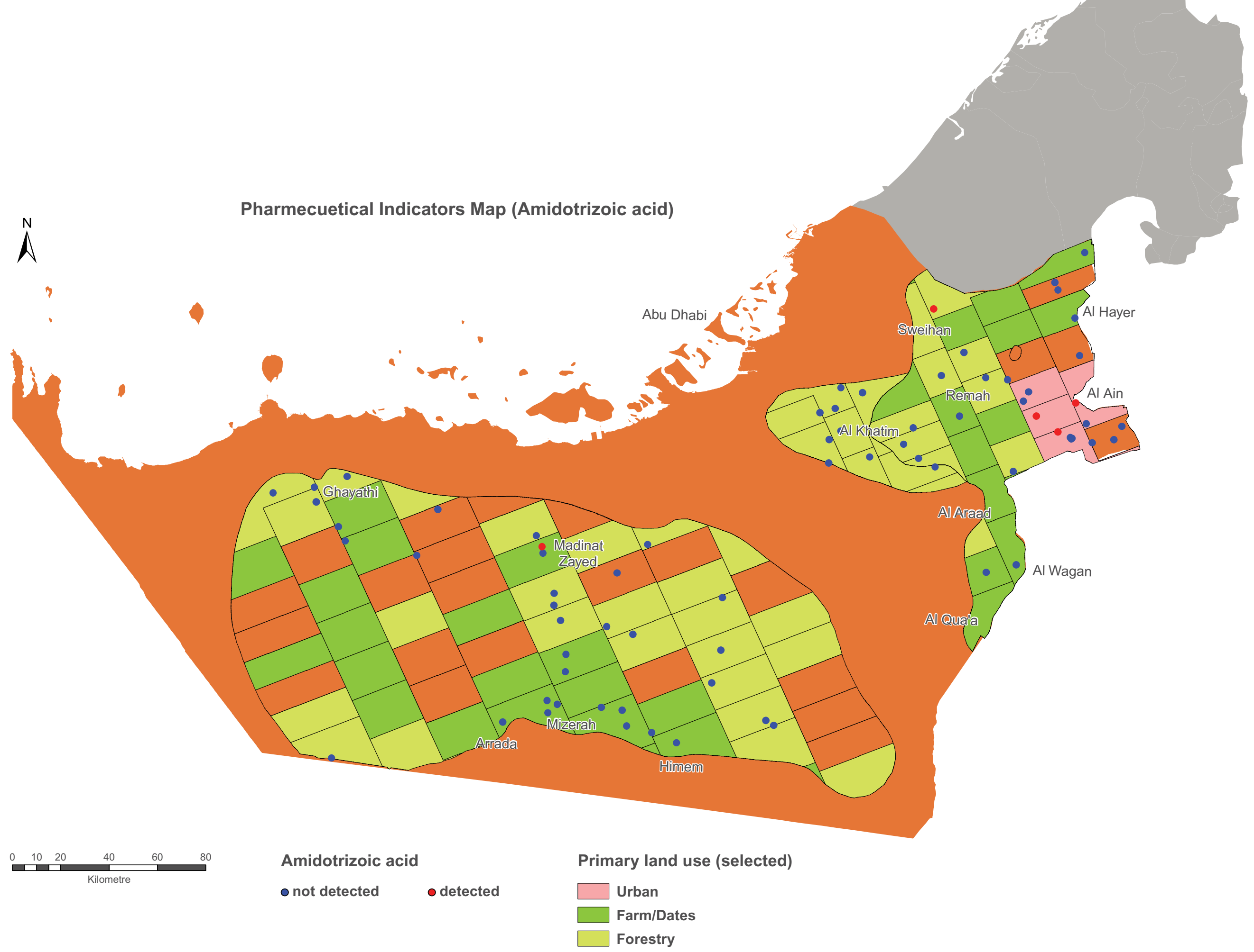

Figure 13: Pharmaceutical indicators detection map.

The three highest concentrations were found in urban settings. Moreover, two of the mentioned wells also showed elevated values for Total Coliforms (8 and 58 CFU/100 mL) and a microbiological contamination with Enterococci (30 and 28 CFU/100 mL; see next section). Finally, it is worth mentioning that the well with the highest concentration, is a dug well. This case illustrates an increased vulnerability of this well type, which requires better protection measures.

3.2.3 Microbiology

In terms of QA/QC measures, the microbiological analyses comprised duplicate analyses and the investigation of field blanks. The results for the former showed excellent agreement and in case of the latter, no microbiological contamination was found.

While all *E. coli* tests were negative, some samples were tested positively for total coliforms (12 cases; between 2 and 200 CFU/100 mL), Faecal coliforms (4 cases; between 5 and 58 CFU/100 mL), and Enterococci (14 cases; between 2 and 46 CFU/100 mL). Figure 14 illustrates the distribution of all detected microbiology. Most of the concerned wells (in total 19) are forest or farm wells with some subordinate usage for livestock purposes and in urban settings. Two of the concerned wells already stood out because Amidotrizoic acid was found. Moreover, it is noteworthy that out of the 19 wells, 10 are dug wells, which illustrates that this well type is as expected, particularly prone to microbial contamination.

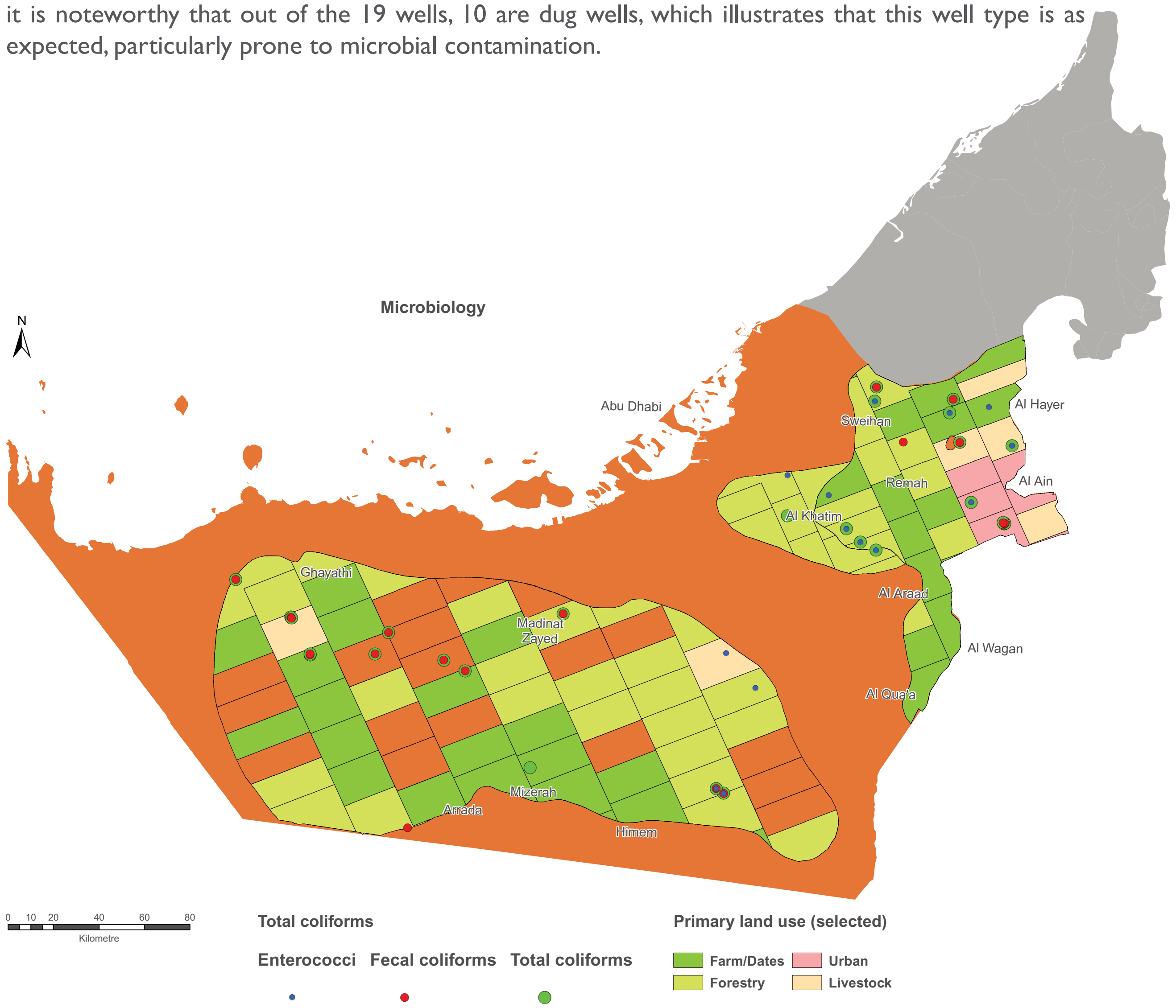

Figure-14: Microbiological sites detection proven map

3.2.4 Dissolved Gases

In terms of the dissolved gases, the encountered results were unremarkable. Oxygen was found in concentrations of a few mg/L. The Methane concentrations were mostly below the detection limit and reached a maximum of 9 µg/L. Nitrogen concentrations ranged between values below the detection limit and 48 µg/L. All CFC and SF6 concentrations were lower than the detection limit of 0.25 µg/L.

Coliforms

Some total coliforms samples were tested positively while all *E. coli* tests were negative

10 out of 19

Wells with detected microbial were dug wells

04

Groundwater uses and quality indices

Integral analysis of several key parameters by means of so-called water quality indices. This index has the crucial advantage that it can be adapted to local conditions and the standards for the most relevant parameters can be integrate. It has calculated with regard to potential uses, namely domestic (non-potable) use, irrigation purposes, and livestock watering. Map was created, in which the four numerical Water Quality Indices (domestic, non-potable; irrigation; livestock, camels; livestock, sheep) are combined and illustrated in Figure 15.

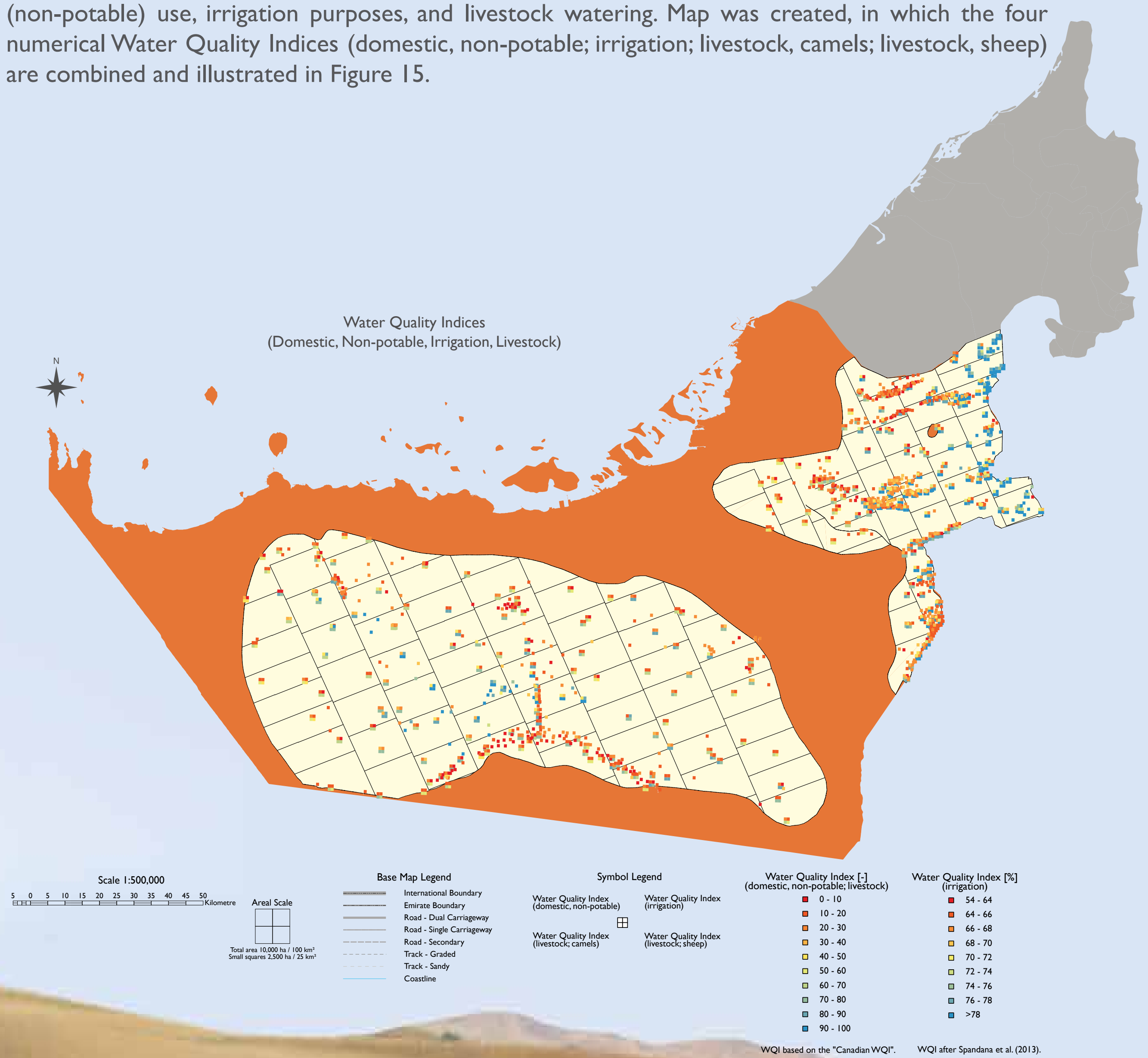

Figure 15: Water Quality Indices map

05

Conclusion and way forward

Exceedances

The monitoring programme identified exceedance in Chromium, Boron and Selenium

7 Types

of pesticides indicators were detected in the agricultural zones

The findings

of this study will be shared with the key stakeholders for their future contribution in any relevant action plan

The 2018 groundwater quality monitoring identified a few sites with exceedances in parameter concentration of natural sources like Chromium, Boron, and Selenium. Special relevant studies were proposed to understand such findings like mineralogical or geochemical study of the metamorphic rocks along the border with Oman as a potential source of Chromium.

In addition, several parameters of anthropogenic sources were proven existing related to different types of land uses, for example, pharmaceutical components were detected in the residential areas and within TSE irrigated areas. 7 types of pesticides indicators were detected in the agricultural zones. While Nitrate, of various concentrations, was detected, seemingly from both natural and anthropogenic sources.

On the other hand, few gaps relevant to groundwater origin and aging were identified, hence a precipitation monitoring scheme was suggested to study the isotopic and chemical composition of rain to assess the isotopic fingerprint of precipitation for comparison in groundwater studies. Moreover, data on chloride in rain could be harnessed for recharge estimations using the Chloride Mass Balance method.

In fact, the aforementioned findings were interpreted by other environmental monitoring programmes particularly Soil, the soil in many sites was identified as a receptor of some heavy metals like Selenium that comes from irrigation of saline groundwater origin, where groundwater was a receptor of Nitrate in the agricultural areas through soil. Both cases were proven through the interpretation of groundwater and soil monitoring data together.

After the completion of the first round of groundwater-quality monitoring, and in accordance with the design of groundwater-quality monitoring that recommended repeating identical monitoring every 3 years; the groundwater monitoring section at EAD will repeat the first round identically in order to closely assess the quality trend. Consequently, a target groundwater-monitoring plan should be developed and implemented, the target monitoring should categorise the pre-selected sites to set the sampling frequency and specify the parameters that should be analysed in the lab. In 2019 and 2020.

Based on the above, and in accordance with a management decision, the finding from this study will be shared with all external stakeholders as a step towards a future extensive action plan to protect groundwater and stop the potential sources of contamination. A detailed groundwater protection action plan is anticipated after the completion of the third monitoring round of groundwater quality that ensure science driven actions based on extensive validated environmental data.

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