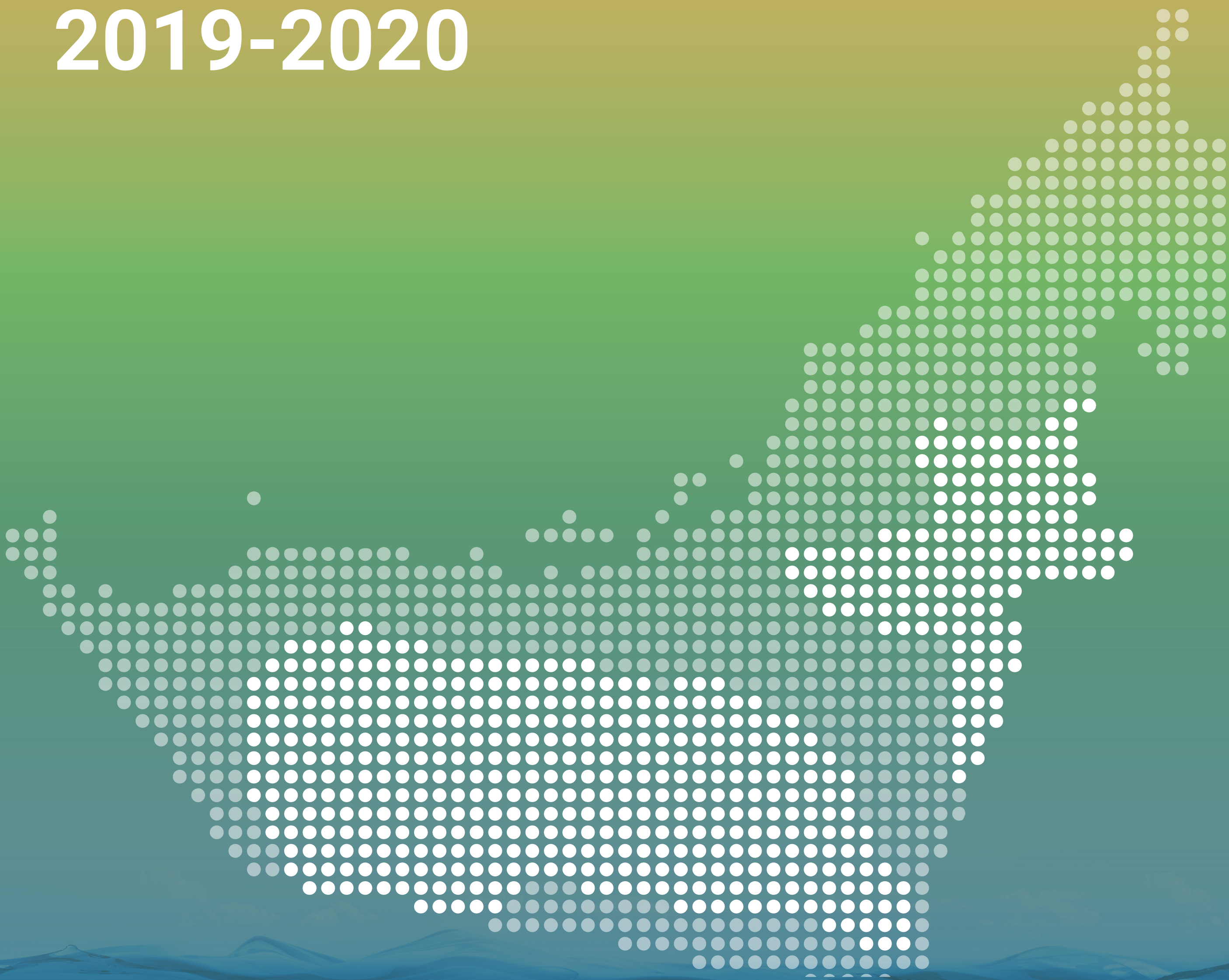
TREND ASSESSMENT OF GROUNDWATER QUALITY IN ABU DHABI EMIRATE 2019-2020



FINAL SUMMARY REPORT
OCTOBER 2020

CONTENT

Abbreviations:

^{226}Ra	Radium-226
^{228}Ra	Radium-228
^{222}Rn	Radon-222
µS/cm	micro Siemens per centimeter
Alk	Alkalinity
b.d.l.	below detection limit
BOD	Biological Oxygen Demand
Bq	Becquerel
CBE	Charge Balance Error
CFU	Colony Forming Units
COD	Chemical Oxygen Demand
DOC	Dissolved Organic Carbon
Dom.	Domestic
EC	Electrical Conductivity
FAO	Food and Agriculture Organization
GLV	Guideline value
HDPE	High-density polyethylene
Hex.	Hexavalent
Irr.	Irrigation
NDMA	N-Nitrosodimethylamine
QA	Quality Assurance
QC	Quality Control
SAR	Sodium Adsorption Ratio
S_y	Specific yield
TDS	Total Dissolved Solids
TOC	Total Organic Carbon
Tot.	Total
WHO	World Health Organization
WQI	Water Quality Index
WTF	Water Table Fluctuation (method)

1 INTRODUCTION

Following optimisation of the groundwater monitoring programme in 2016 and the subsequent Groundwater Quality Baseline Survey project in 2018, the Environment Agency - Abu Dhabi (EAD) analysed the trend of all groundwater constituents (Natural & Anthropogenic) within the frame of the *Trend Assessment of Groundwater Quality in Abu Dhabi Emirate*.

The main objective was to sample, analyse and assess groundwater qualities in the Abu Dhabi Emirate, with the main emphasis being on the Eastern and Western Monitoring Sub-Area (Al Ain and Al Dhafra region).

In the following, key findings and results for both regions, are summarised hereinafter.

EAD is operating a Groundwater Quality Monitoring (GWQM) Programme since 2005 to assess the changes in groundwater quantities and qualities.

Due to increasing pressure on groundwater resources, the groundwater quality trend in the Emirate of Abu Dhabi shall be assessed, particularly, within areas with directly useable groundwater zones.

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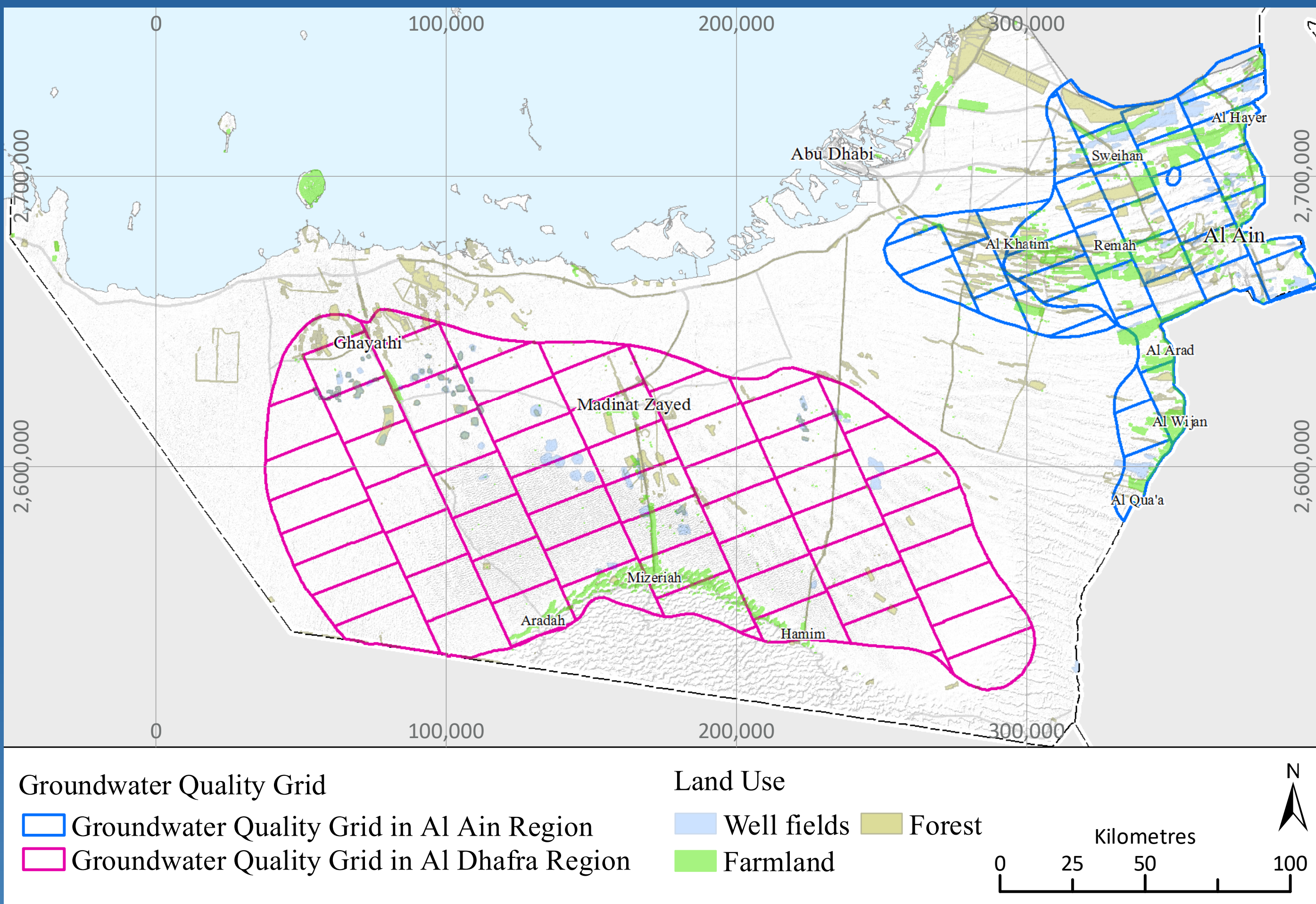
To conduct trend analysis of all groundwater constituents and provide the relevant interpretation, the groundwater quality monitoring programme comprises of:

1. ASSESSMENT OF THE GROUNDWATER QUALITY
2. ASSESSMENT OF CONTAMINATION
3. ENHANCEMENT OF SALINITY MONITORING



The area of this campaign lies within the Groundwater Quality Grid of Abu Dhabi Emirate, which is designed to monitor groundwater quality of the surficial aquifer across the Emirate and of the water bearing formations underlying the surficial aquifer.

2 FIELDWORK

Groundwater samples were collected from the same wells which were already sampled during the Groundwater Quality Baseline Survey, in 2018 as illustrated below. When pre-selected wells were inaccessible for sampling, a suitable replacement well was identified and sampled instead.

139 WELLS

SELECTED FOR SAMPLE COLLECTION

16 ADDITIONAL WELLS

SELECTED FOR QUALITY ASSURANCE

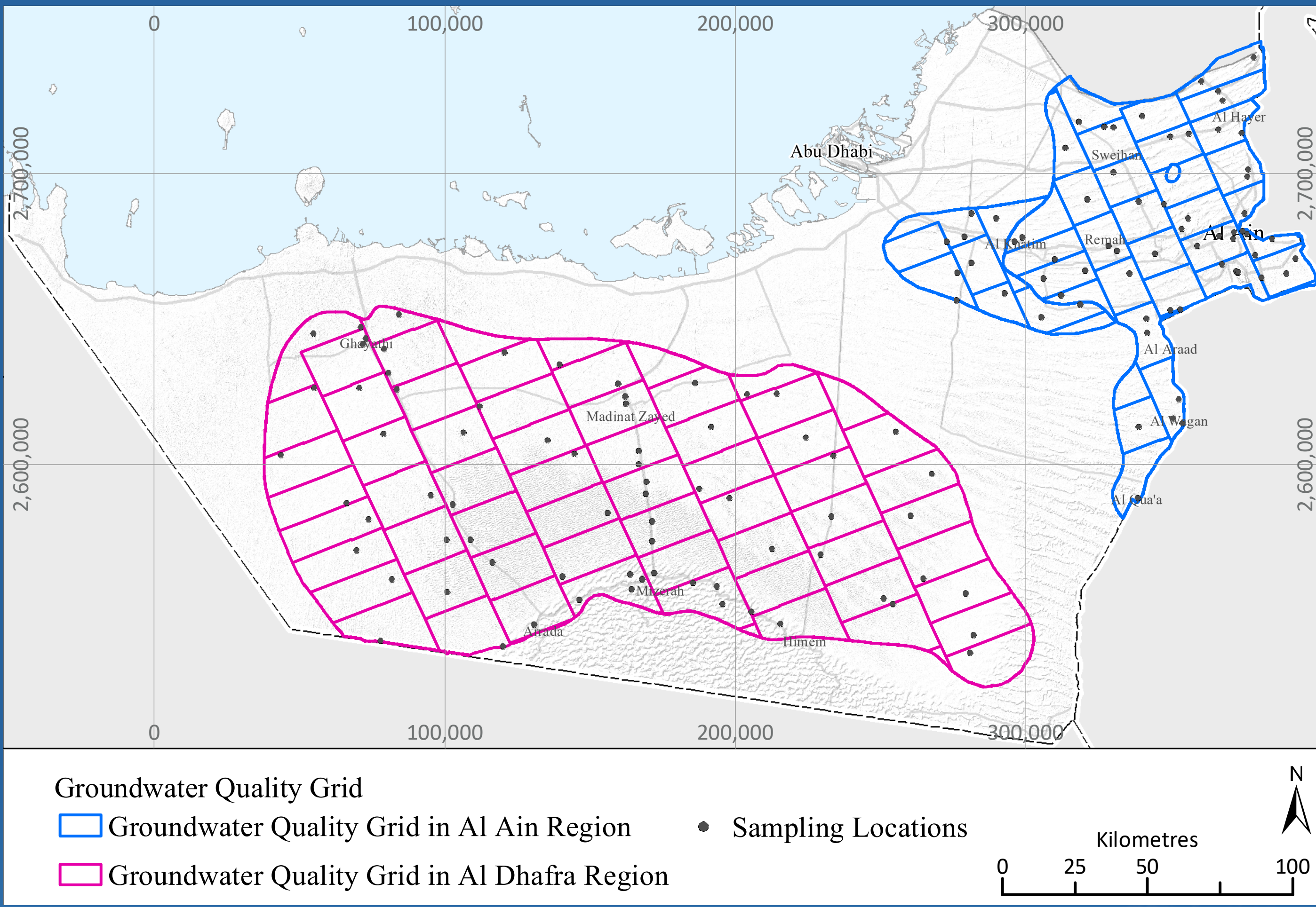
Sampling took place from November 2019 to February 2020. 66 wells were selected from Eastern Monitoring Sub-Area and 73 wells from Western Monitoring Sub-Area. An additional 16 samples, equivalent to approximately 10 % per region were taken for quality control measures making the total samples taken 155.

Fieldwork accomplished by two sufficiently-trained sampling teams and guided by a team supervisor collected samples for hydrochemical analyses, *i.e.* major anions/cations, trace elements, microbiology, pesticides, pharmaceuticals and radionuclides. During the sampling process, different sample bottle types (*e.g.* glass, HDPE, *etc.*) and sizes were used dependent upon various parameters as will be summarised below.

Throughout the sampling campaign, EAD Standard Operating Procedures for Groundwater Sampling were followed.

During each site visit, various field data was recorded *e.g.* well type, dimensions, casing material together with the execution of *in-situ* measurements comprised water table, electrical conductivity, pH, dissolved oxygen, turbidity, alkalinity and hydrogen sulphide.

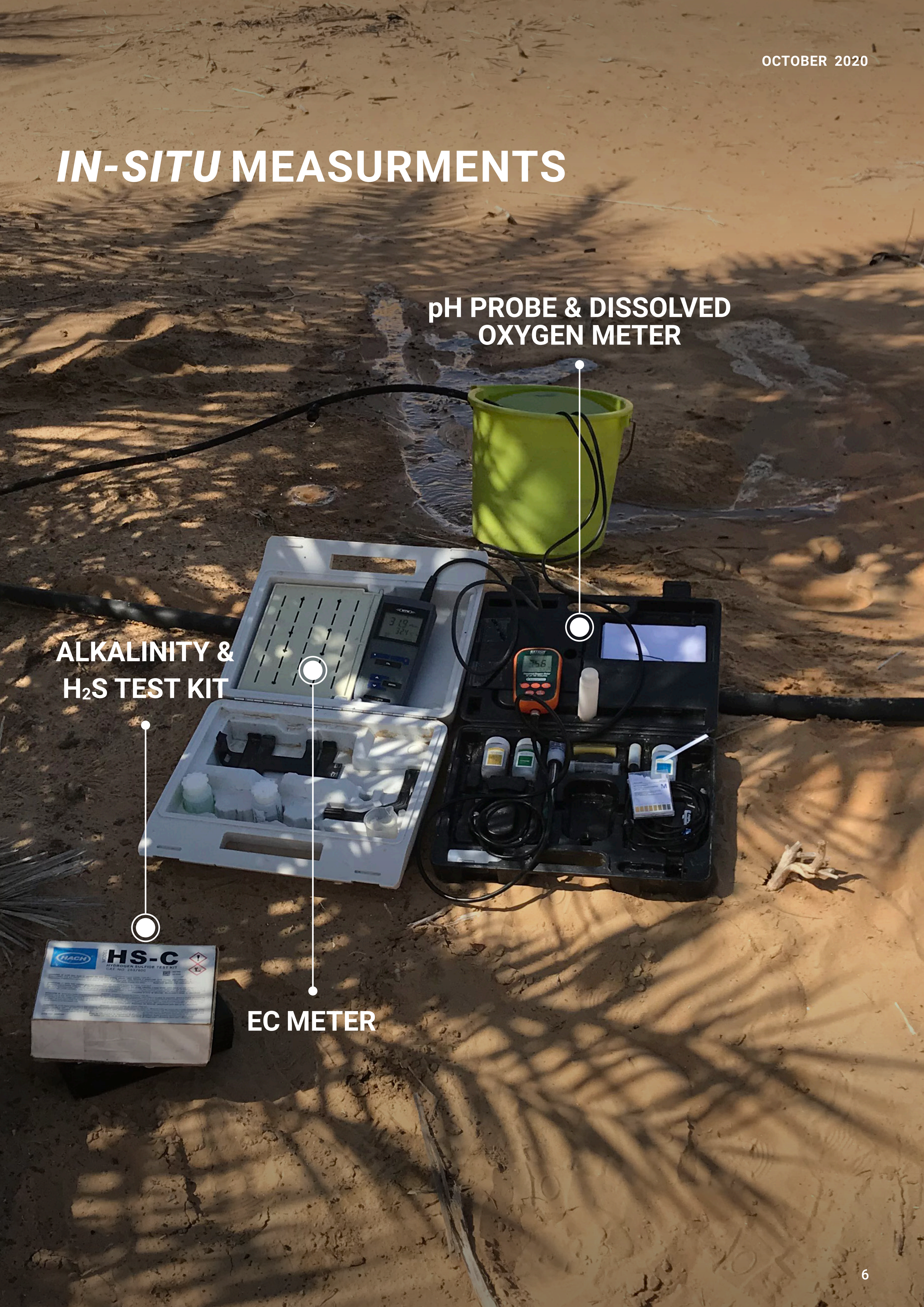
The sampling approach for each well depended on various parameters such as the well status and well type, *i.e.* Operational or Idle. When Idle wells were encountered, the field crew installed a mobile pump as illustrated below.

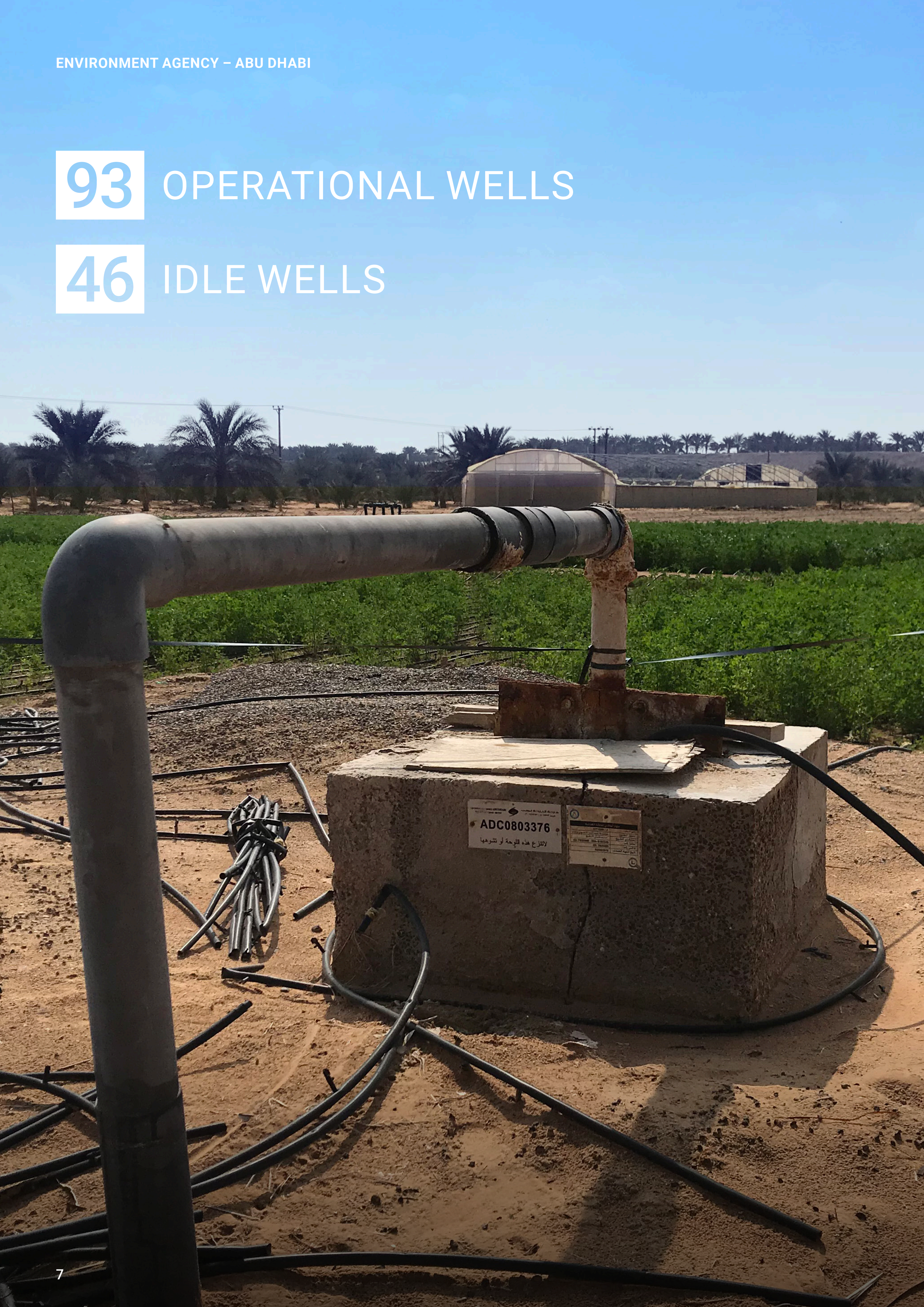


In-situ measurements were taken prior to the execution of groundwater sampling. Sampling equipment was cleaned between locations to prevent cross contamination, and mitigate staff exposure to potential contaminants.

A chain-of-custody form was implemented for each sampling bottle and clearly marked showing sample ID, date and time, number of bottles per samples, parameter to be analysed, on-site results and the name of technician taking the sample.

IN-SITU MEASURMENTS





93 OPERATIONAL WELLS

46 IDLE WELLS

After the process was completed and samples appropriately stored (*i.e.* placed in a cooler box filled with ice packs, *etc.*), the samples were handed over to the Laboratory within the allowed holding time.

An accredited laboratory according to DIN EN ISO / IEC 17025, certified through the Emirates National Accreditation System (ENAS) and listed with the Abu Dhabi Quality and Conformity Council (ADQCC) was selected.

The Laboratory analysis was conducted from December 2019 to April 2020.

The sampled parameters are shown in the following table.

Pharmaceutical products, NDMA and wastewater indicators were analysed from the same 55 wells, as for the Groundwater Quality Baseline Survey (2018).

8 DUPLICATE SAMPLES AND 4 FIELD BLANK SAMPLES.

For Radionuclides, all wells were included in the analysis of ^{226}Ra and ^{228}Ra to detect and monitor naturally occouring radioactivity of groundwater.

OVERVIEW OF PARAMETERS ANALYSED BY THE LABORATORY.

ITEM	GENERAL CONSTITUENT CATEGORY	SAMPLED CONSTITUENT(S)	QUANTITY
8		Ferrous iron	155
9		Major cations	155
10	Basic Ions	Major and minor anions	155
11		Nutrients (N and P compounds)	155
12	Trace Metals	Trace elements/metals including Chromium (total and VI)	155
13a		Total coliform, Escherichia (*E . coli*)	155
13b	Bacteria	Replicate sample Total coliform, Escherichia (*E. coli*)	8
13c		Field blank Total coliform, Escherichia (*E. coli*)	4
14	DOC/TOC	Dissolved/total organic carbon	155
15	Pesticides	Pesticides	155
17		Wastewater indicators	
18	Wastewater Reuse	Pharmaceutical products	55
19		N-nitrosodimethyl amine (NDMA)	
20	Radio-nuclides	Radium isotopes (^{226}Ra & ^{228}Ra)	155

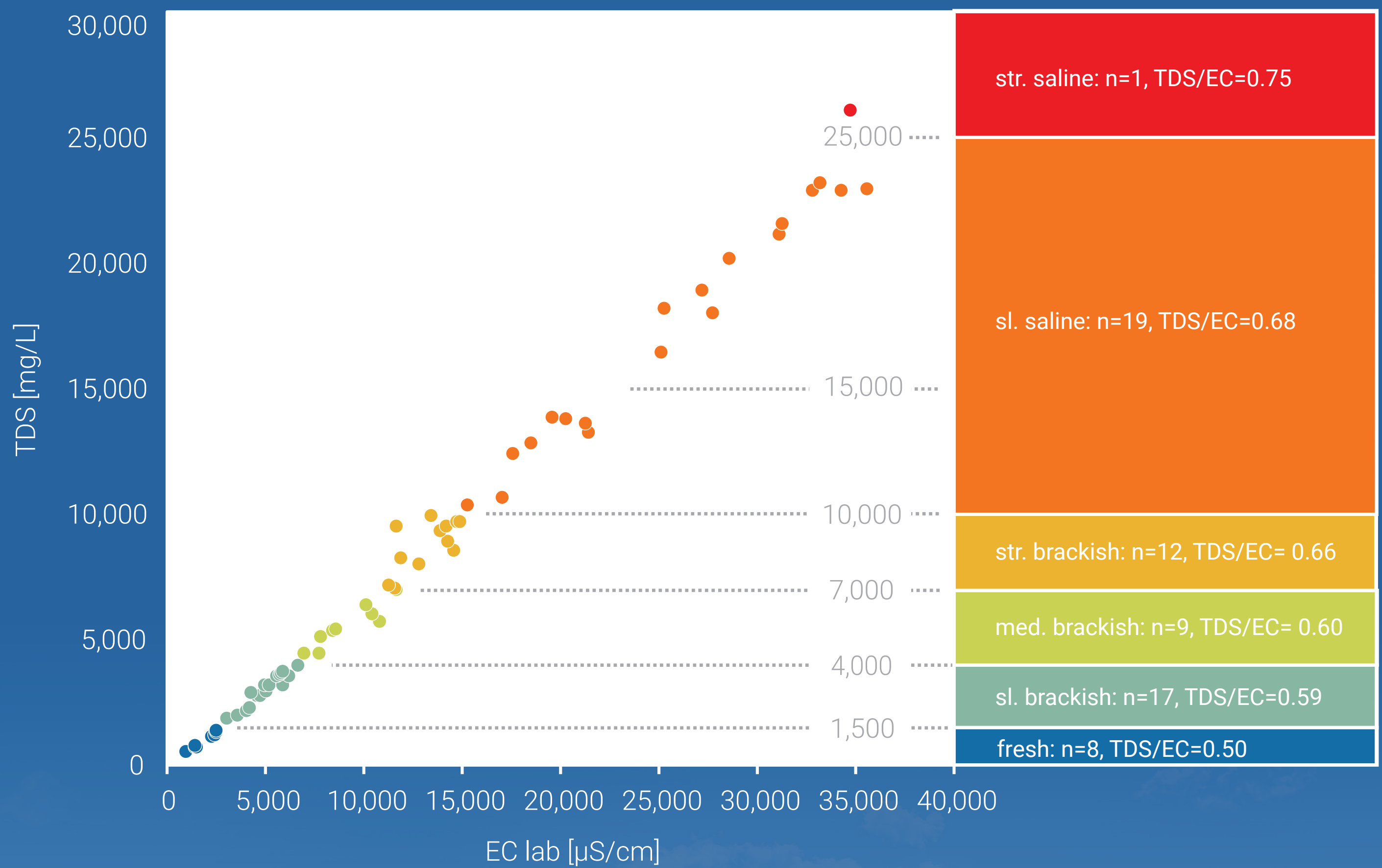
FIELD BLANKS & REPLICATE SAMPLES

FOR QUALITY ASSURANCE

10% SAMPLES COLLECTED
FOR QUALITY ASSURANCE

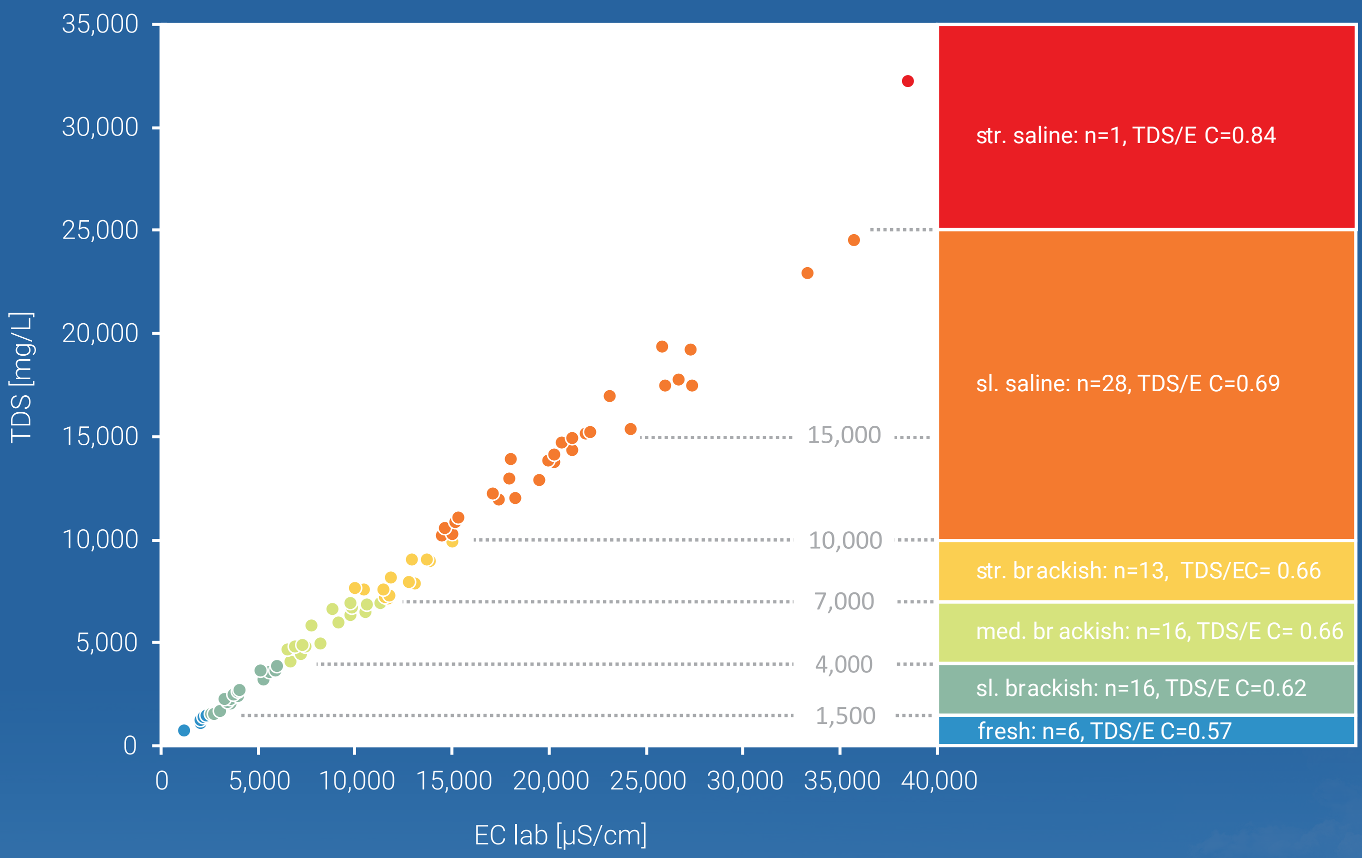
3 INTERPRETATION OF GROUNDWATER ANALYSES

3.1 BASIC PARAMETERS



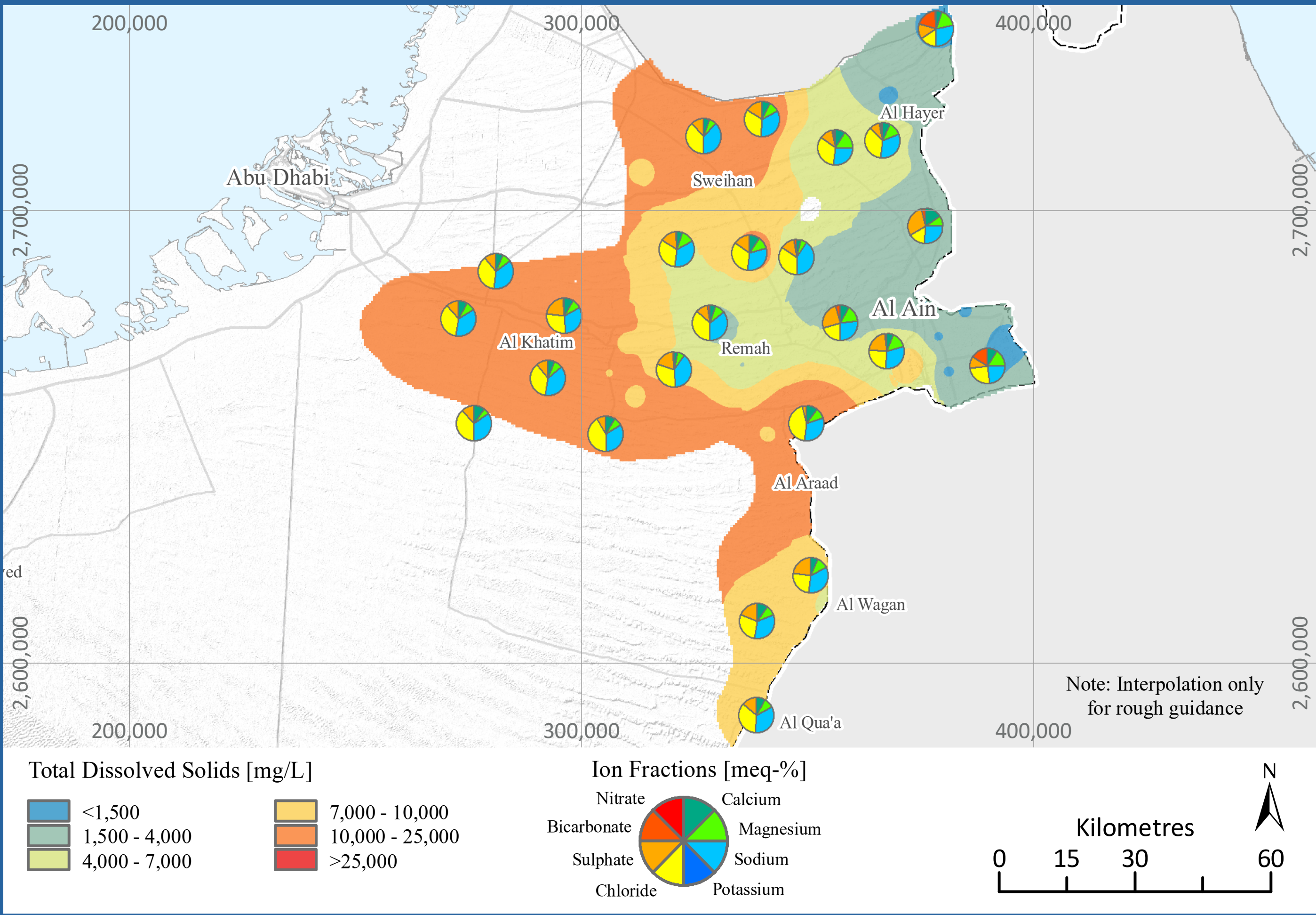
EASTERN MONITORING SUB-AREA

The internal QA/QC measures implemented by the lab were complemented by own plausibility checks comprising of blank and duplicate analyses (**where validated**), the calculation of charge balance errors (all errors within ± 5 %), and the correlation between parameters that were measured in the field and in the laboratory (**where validated**). Moreover, related parameters were compared. Examples for the latter are given in the following figures.



WESTERN MONITORING SUB-AREA

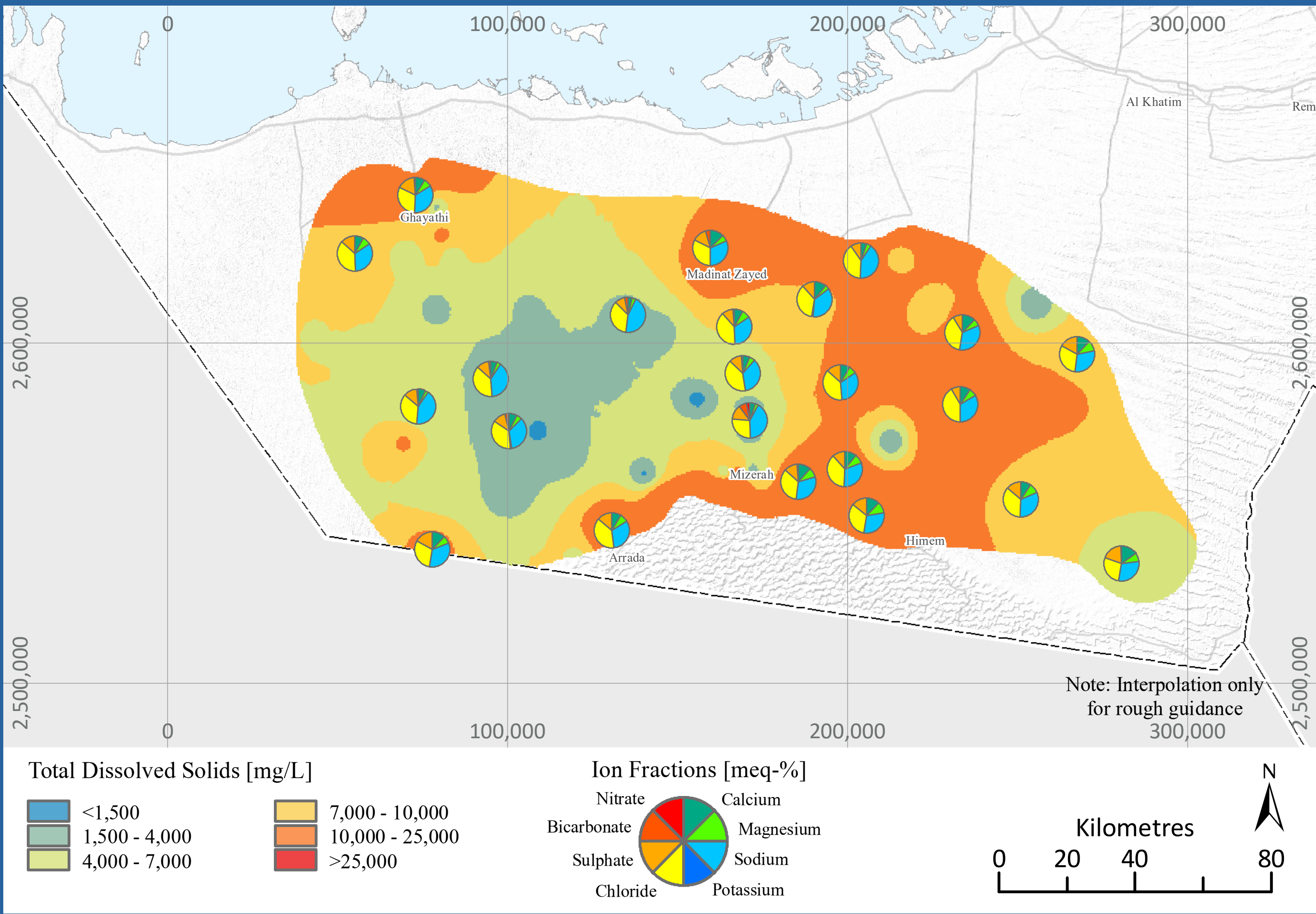
Aside from illustrating excellent correlation, the charts also depict the wide range of encountered salinities, covering the following classes of the UAE salinity scheme (numbers refer to the Eastern and Western Monitoring Sub-Area, respectively); fresh (8 and 6 samples), slightly brackish (17 and 16 samples), medium brackish (9 and 16 samples), strongly brackish (12 and 13 samples), slightly saline (19 and 28 samples), and strongly saline (1 sample each). Notwithstanding, overall salinities are rather high. In case of the the Eastern Monitoring Sub-Area, 62 out of 66 values exceed the EAD (2017) guideline value of 1,000 mg/L for domestic purposes. In the Western Monitoring Sub-Area, 72 out of 73 concentrations exceed this value.



Fresher waters appear to be more prevalent in the most eastern part of the Eastern Monitoring Sub-Area, along the border with Oman. Towards the West, *i.e.* down-gradient, the groundwater becomes more saline. This trend has also been observed in the Groundwater Quality Baseline Survey (2018), which considers good groundwater recharge consequent of fresh water in and around the mountains. This area is renowned to typically receive more rainfall, with the high infiltration capacities of the commonly gravel-dominated plains bordering the mountains favouring such replenishment.

In the Western Monitoring Sub-Area, fresher waters are more prevalent in the central part of the study area, mainly north and northwest of the Liwa Crescent. In the peripheral parts of the study area, *i.e.* down-gradient, the groundwater becomes more saline. This pattern has also been observed in the Groundwater Quality Baseline Survey (2018) and is thought to reflect a fresh water mound. Its formation was probably facilitated by the high infiltration capacities of the sandy dune and interdune areas.

The calculation of relative changes since the last campaign yielded both upside and downside fluctuations. Since 2019 was a particularly wet year (with sustained rainfalls and flooded streets), decreases in TDS would appear to be linked to recent recharge activity.



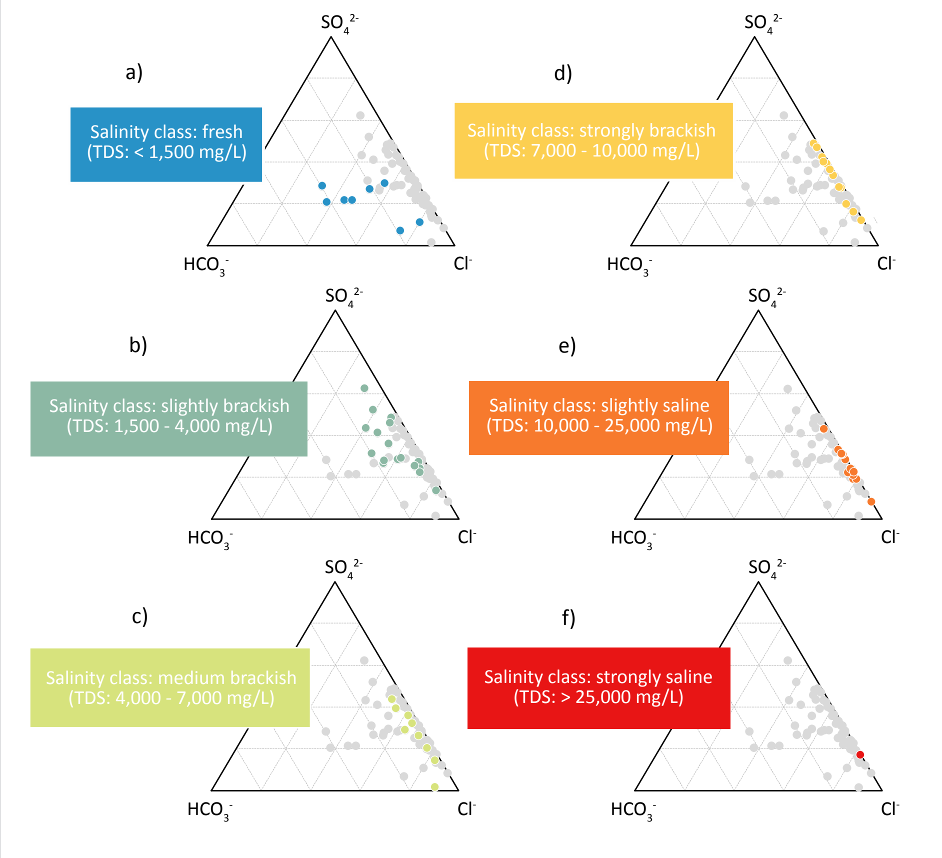
Among the ions contributing to the total salinity, Sodium and Chloride are the most dominant, with Magnesium and Sulphate also showing significant salinity contributors. Accordingly, Na-Cl-SO4 is the most common water type in both study areas (25 and 44 samples). In the Al Ain area, other important water types comprise Na-Mg-Cl-SO4 (15 samples), Na-Cl (7 samples), and Na-Ca-Cl (4 samples). In the Western Monitoring Sub-Area, the water types Ca-Cl-SO4 (19 samples) and Na-Cl (6 samples) are worth mention. The remaining water types play a lesser commonality role.

In considering, which water type prevails in a given area also depends on the salinity of the water. This is illustrated in the following figures, in which several anion ternary plots are combined. Fresh waters show a somewhat balanced anion pattern, with significant bicarbonate shares. Conversely, with increasing salinity, bicarbonate becomes less important and accordingly sulphate and especially chloride play a greater role.

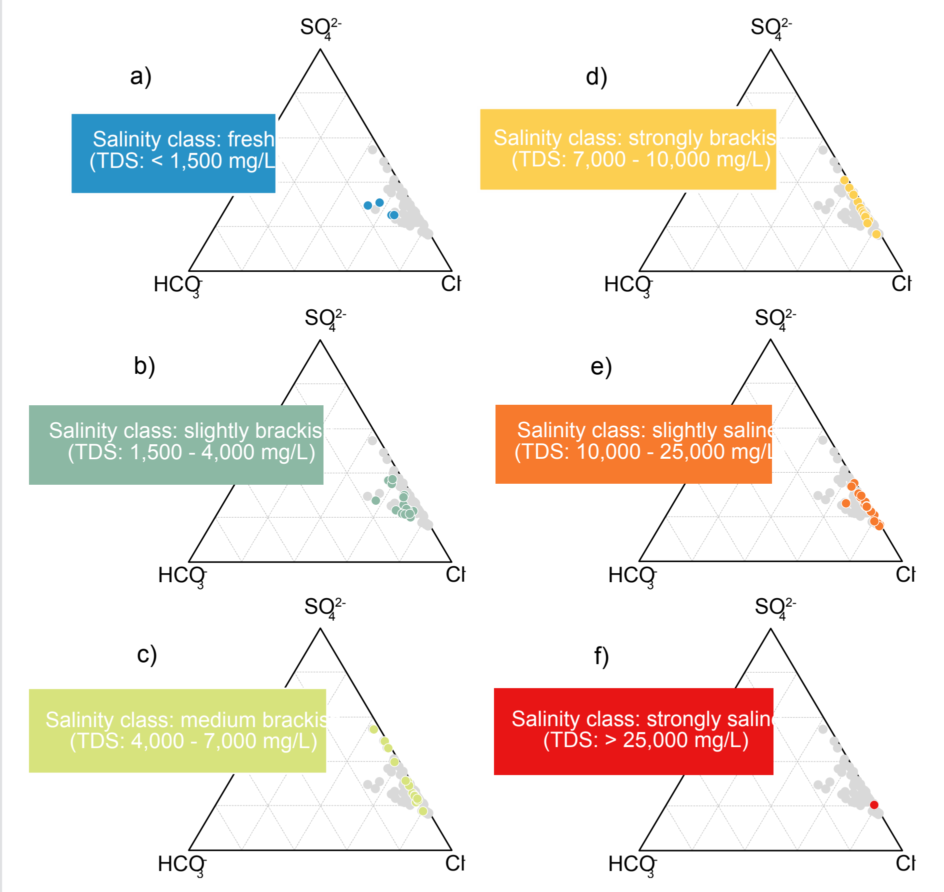
Correlation analyses as illustrated in the below matrices revealed that several basic parameters are inter-related, with respect to their concentrations and concentration changes.

The correlation matrices reveal strong positive correlations among the major ions Calcium, Magnesium, Sodium, Potassium, Chloride, Sulphate, and the TDS, which is a common phenomenon. If the total salinity is high, most major ions will be enriched as well.

EASTERN MONITORING SUB-AREA



WESTERN MONITORING SUB-AREA



Although Bicarbonate is also considered a major ion, it does not follow the same trend with the data indicating a partly negative correlation. This is predominantly due to the relatively low solubilities of carbonate minerals, which imply that Bicarbonate concentrations cannot rise proportionately during salinization.

EASTERN MONITORING SUB-AREA

	TDS	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Cl^{-}	SO_4^{2-}	HCO_3^{-}	Br^{-}	NO_3^{-}
TDS	1									
Ca^{2+}	0.90	1								
Mg^{2+}	0.92	0.82	1							
Na^{+}	0.98	0.84	0.90	1						
K	0.94	0.84	0.85	0.94	1					
Cl^{-}	0.99	0.89	0.91	0.98	0.93	1				
SO_4^{2-}	0.84	0.73	0.82	0.82	0.77	0.75	1			
HCO_3^{-}	-0.31	-0.30	-0.26	-0.28	-0.25	-0.29	-0.31	1		
Br^{-}	0.31	0.50	0.30	0.27	0.28	0.40	-0.07	-0.09	1	
NO_3^{-}	-0.02	-0.05	0.12	-0.03	-0.04	-0.03	0.03	0.01	-0.03	1

Color 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...

WESTERN MONITORING SUB-AREA

	TDS	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Cl^{-}	SO_4^{2-}	HCO_3^{-}	Br^{-}	NO_3^{-}
TDS	1									
Ca^{2+}	0.89	1								
Mg^{2+}	0.90	0.93	1							
Na^{+}	0.98	0.81	0.82	1						
K^{+}	0.84	0.76	0.74	0.80	1					
Cl^{-}	0.99	0.85	0.88	0.98	0.81	1				
SO_4^{2-}	0.93	0.89	0.90	0.87	0.82	0.87	1			
HCO_3^{-}	0.12	0.18	0.13	0.08	0.22	0.09	0.15	1		
Br^{-}	0.18	0.19	0.21	0.11	0.36	0.16	0.23	0.10	1	
NO_3^{-}	0.46	0.54	0.56	0.39	0.37	0.41	0.57	0.08	0.11	1

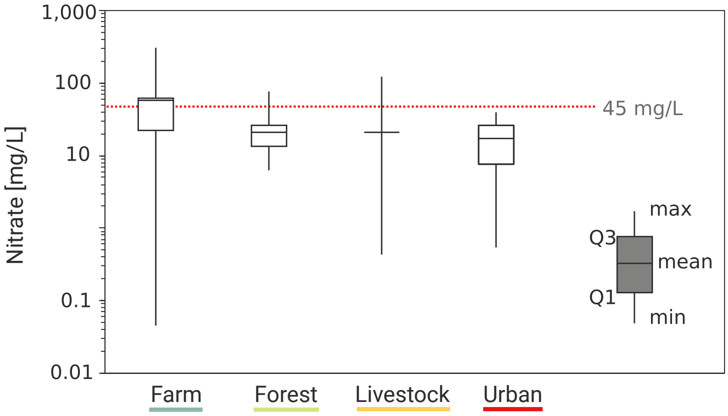
Color legend

-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...

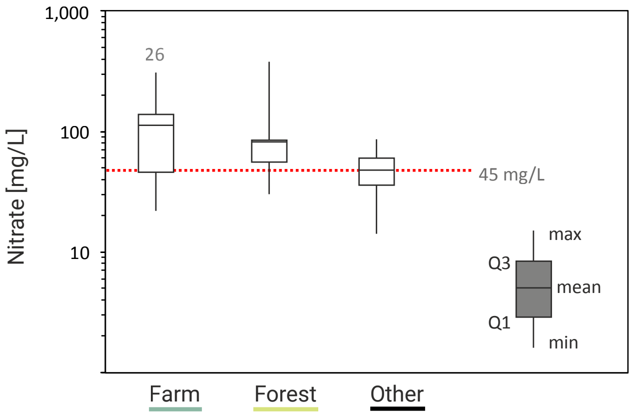
The light colours in the Nitrate line reflect low correlation coefficients, indicating that this anion is decoupled from the other constituents. Its abundance is not a function of salinity, instead, it is contamination-controlled.

3.2 NITRATE

In the Eastern Monitoring Sub-Area, the variation of Nitrate concentrations ranges between levels below the detection limit and 310 mg/L. Its mean value amounts to 34 mg/L. Considering the EAD (2017) guideline value for domestic use of 45 mg/L, guideline violations are encountered in a total of 11 water samples.



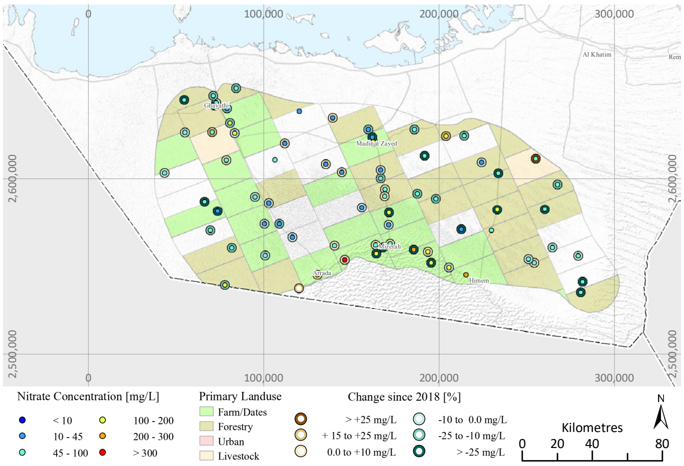
EASTERN MONITORING SUB-AREA

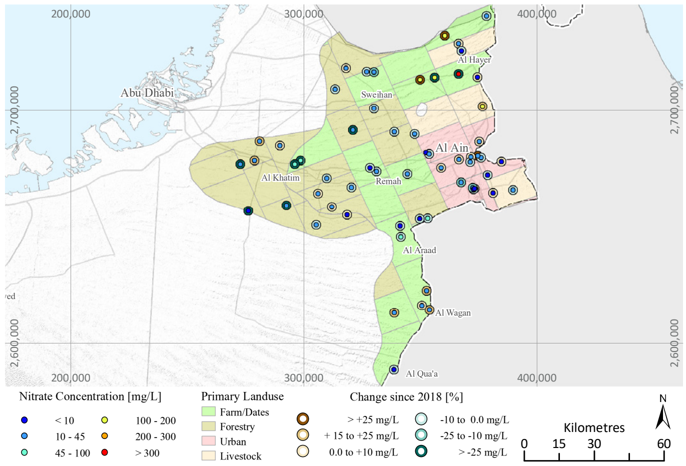


WESTERN MONITORING SUB-AREA

Above reveals an appreciable scatter within each land use class, but the wells in farm-dominated cells show higher values on average. The greatest number of EAD (2017) guideline value violations is encountered and even the mean value exceeds the threshold of 45 mg/L (for domestic, non-potable use).

In terms of the Western Monitoring Sub-Area, the Nitrate concentrations range between 14 and 380 mg/L and the mean value amounts to 84 mg/L. The EAD (2017) guideline value for domestic use is violated in a total of 54 samples.



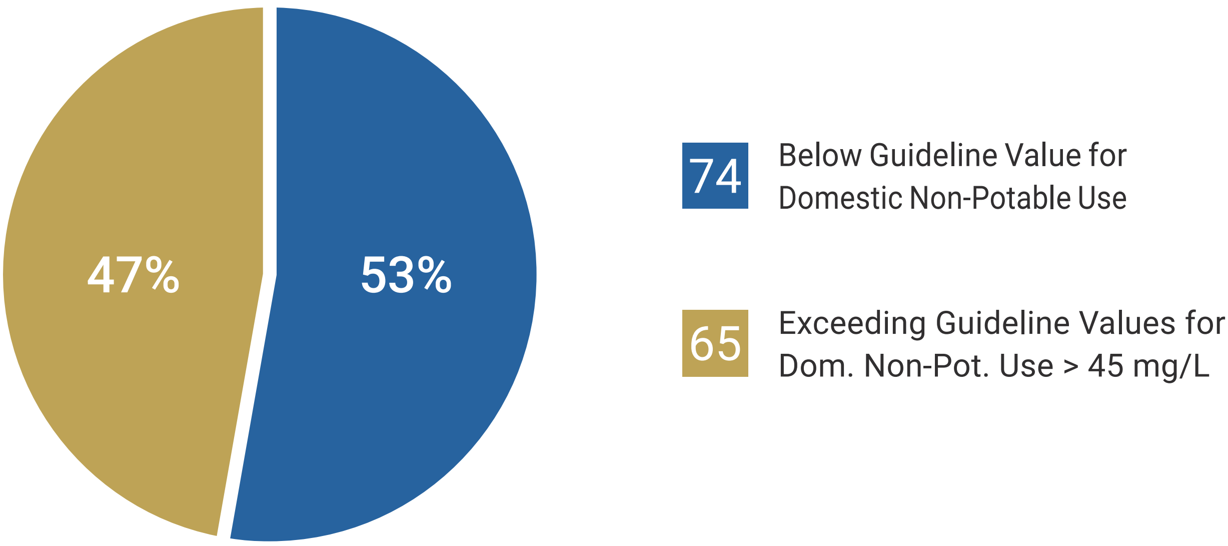


Each land use class shows a remarkable Nitrate variation, but the wells in farm-dominated cells exhibit the highest average concentration (112 mg/L). The maximum value, however, was encountered in a forestry-dominated cell (380 mg/L).

In both land use classes, the mean concentration clearly exceeds the EAD (2017) guideline value (for domestic, non-potable use). Nitrate concentrations that are associated with other land uses scatter around the threshold and the corresponding mean value (48 mg/L) falls close to the threshold.

In view of these findings, it would seem that fertilisers used in agricultural settings play an important role in the Nitrate context.

NITRATE GUIDELINE VIOLATIONS



3.3 TRACE ELEMENTS

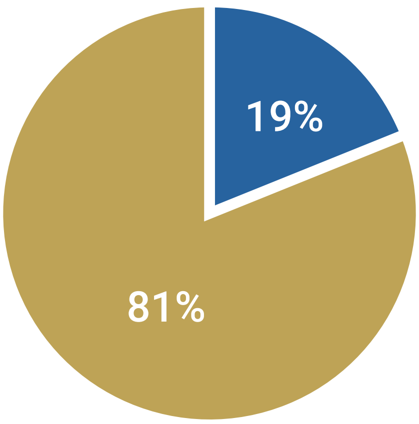
Most trace elements show a rather vast scatter, which is in line with the distinct salinity variations and the presence of a range of water types. Only individual values show elevated concentrations. Concentrations of Arsenic for instance fall mostly below 10 µg/L, with the exception of one sample from the Eastern Monitoring Sub-Area (48 µg/L) and one from the Western Monitoring Sub-Area (55 µg/L). Both concentrations violate the guideline values for domestic and livestock use (18 µg/L and 25 µg/L, respectively). It has to be stressed that the concerned wells showed similar concentrations in the previous project.

With regards to Boron and Chromium however, the cases are more severe – in both study areas. Boron concentrations average around 2,620 µg/L in the Eastern Monitoring Sub-Area and around 3,453 µg/L in the Western Monitoring Sub-Area. The mean Chromium concentrations amount to 137 µg/L and 184 µg/L, respectively.

Elevated Boron concentrations are harnessed as wastewater indicators and are sometimes present in fertilisers. Further, Boron can be associated with desalination units. The number of guideline violations is strongly dependent on which guideline value is considered, with thresholds for the different uses differing vastly. They range between 500 µg/L (irrigation) and 5,000 µg/L (livestock watering).

As for Chromium, the concentrations range from 1 to 2,011 µg/L in the Eastern Monitoring Sub-Area. A total of 41 samples exceed the guideline value of 50 µg/L for domestic, non-potable use. Lower values are generally clustered around the City of Al Ain with increasing concentrations towards the west. In the the Western Monitoring Sub-Area, Chromium concentrations range from 11 to 443 µg/L. Here, the guideline value of 50 µg/L for domestic, non-potable use is violated in 71 samples.

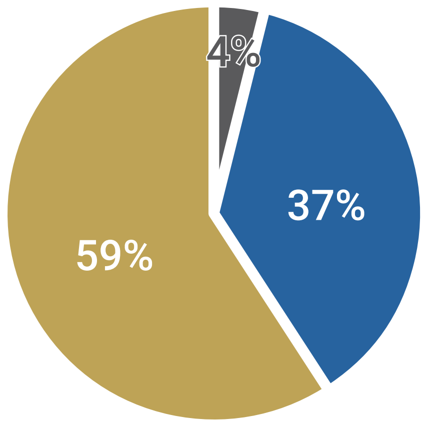
CHROMIUM



2 Below Guideline Value for Domestic Non-Potable Use

112 Exceeding Guideline Values for Dom. Non-Pot. Use > 50 µg/L

BORON



5 Below Guideline Value for Agricultural Irrigation [<0.5 mg/L]

52 Below Guideline Value for Domestic Non-Potable Use but exceeding the Guideline Value for Agricultural Irrigation (>0.5 mg/L to 2.4 mg/L)

82 Exceeding both Guideline Values (> 2.4 mg/L)

Based on groundwater quality data obtained during this round of this study and the previous round, it is confirmed, that the overall water character largely remained the same. Nevertheless, some parameters showed significant changes in some wells and the following potential processes may play a role:

- Recent (natural) groundwater recharge: Usually this will have a dilution effect, but also the opposite is, in principle, possible (flushing of accumulated salts from the unsaturated zone),
- Effects caused by irrigation practices (intentional salt flushing, unintentional irrigation return flow),
- Contamination through the (uncovered) well itself (*e.g.* drifting sand),
- Collapsed sections or blown-in sand possibly isolating previously contributing zones,
- Upconing of salty water,
- Well maintenance/rehabilitation,
- New pump/modified discharge,
- Changed pump position.

While the exact underlying process cannot be identified for each case, it is pertinent to note that several of the most extreme concentration changes were found for shallow idle wells, which were either not or not sufficiently covered, highlighting a certain aquifer vulnerability. This conclusion is emphasised by new microbiological contaminations – *E. coli*, an indicator for faecal contamination was encountered in four wells (two in each study area).

Although human activities can cause water quality deterioration, also natural contaminants were found. Examples comprise several trace elements (Boron, Chromium, Molybdenum, Selenium; several areas), but also the radionuclides Radium-226 (three wells in the Jabel Hafit area) and Radium-228 (one case in the Western Monitoring Sub-Area). While the corresponding concentrations showed some fluctuations, the phenomenon was known from the Groundwater Quality Baseline Survey (2018).

In contrast, the pesticide and pharmaceuticals analyses were inconspicuous.

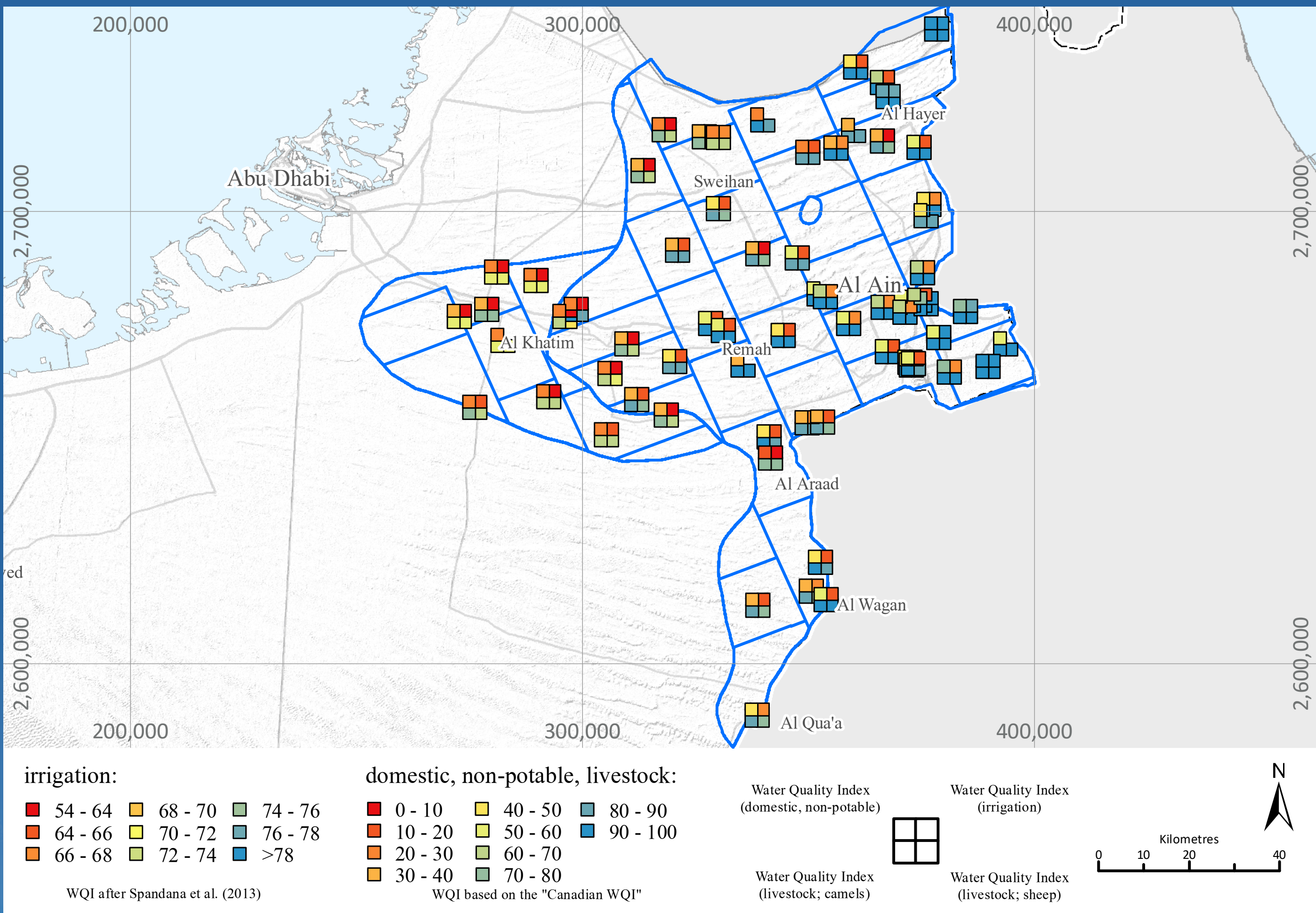
3.4 WATER QUALITY INDICES

In addition to the evaluation of single parameters and their EAD (2017) guideline value violations, water quality was also assessed in an integral way. To this end, several key parameters were combined to calculate so-called water quality indices (WQI). Like in the previous project, WQI values are calculated with respect to the following potential uses:

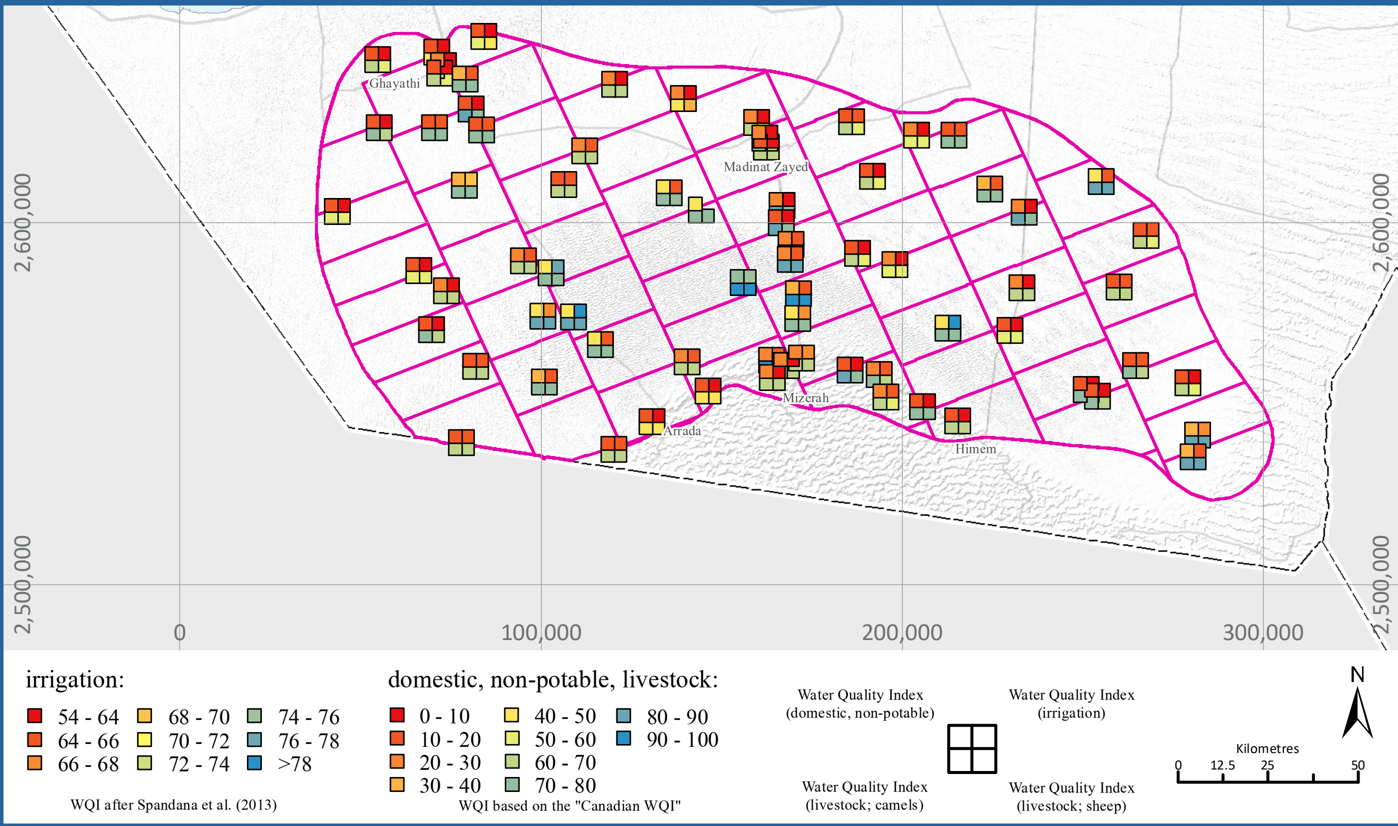
DOMESTIC (non-potable) use

IRRIGATION PURPOSES

LIVESTOCK WATERING



The WQI values for domestic use showed a large range, in the Eastern Monitoring Sub-Area (12 to 100 %; mean: 45 %) and in the Western Monitoring Sub-Area (12 to 72 %; mean: 24 %), reflecting the greatly varying water qualities encountered in this investigation. Not surprisingly, the highest scores were found for the freshest waters, i.e. in the East of the Al Ain area and in the centre of the Western Monitoring Sub-Area. Hence, the overall spatial patterns did not change since the previous project, but on average the WQI increased slightly (from 42 to 45 %) in the Al Ain case. The greatest increases were observed for the Eastern wells for which it was suspected recent recharge activity was a contributing factor (see above). In the Western Monitoring Sub-Area, the WQI remained on average rather stable (slight decrease from 25 to 24 %). Here, the number of wells with a positive and a negative development are balanced.



With respect to irrigation, the groundwater use is rather restricted due to elevated salinities and the associated Sodium dominance. The elevated Boron values (see above) represent a further restriction. The WQI values, combining several relevant parameters, range between 62 and 86 % (Eastern Monitoring Sub-Area; mean: 67 %) and between 56 and 79 % (Western Monitoring Sub-Area; mean: 65 %). While individual wells did show some change, the mean WQI remained the same, *i.e.* overall, individual hydrochemical shifts balanced each other out.

In terms of livestock, two cases were considered, camels and sheep. In the Al Ain case, the WQI values for camel watering range from 56 to 100 % and average at 88 %. A comparison with previous values reveals that the water in the area improved slightly on average (increase of the mean from 84 to 88 %). In the Western Monitoring Sub-Area, the corresponding WQI values range from 43 to 100 % and the mean amounts to 71 %. Since the previous study, the average water quality largely remained the same (slight change from 70 to 71 %).

The overall pattern is very similar for sheep watering. In the Eastern Monitoring Sub-Area, the WQI values scatter between 49 and 100 % and the mean accounts for 84 %. In comparison with the Groundwater Quality Baseline Survey (2018), the average water quality became slightly better (increase of the mean from 81 to 84 %). The WQI values calculated for the Western Monitoring Sub-Area range from 40 to 100 % and the mean accounts for 67 %. Since the previous project, the average water quality remained rather stable (slight increase from 66 to 67 %).

GREATLY VARYING WATER QUALITY INDICES

4 ENHANCEMENT OF GROUNDWATER SALINITY MONITORING

The procurement and installation of 20 telemetric, self-sustaining monitoring devices was also part of this project, and aims to enhance the groundwater salinity monitoring in the whole Emirate of Abu Dhabi.

All data loggers selected for installation were manufactured by SEBA Hydrometrie GmbH & Co. KG and made up of two separate components. The first component is the sensor itself (MPS-PTEC), which takes automatic measurements. A second component (FlashCom) is connected with the sensor to record data (data logger), and to subsequently transmit the data via GSM connection. The FlashCom is equipped with solar modules to allow self-sustaining operation and therefore limits maintenance to a minimum.


PC Interface Cable
FlashCom 3G+
MPS-PTEC
www.seba.de

5 CONCLUSION & WAY FORWARD

GENERAL DECREASE OF TDS

0 PESTICIDES DETECTED

CONTINUED MONITORING

In conclusion, although some parameters and wells did show changes since the last sampling campaign, the overall picture remained the same. The groundwater in the study area is generally salty and several water constituents appear in concentrations that constitute violations of the EAD (2017) guideline values. Prominent examples are Boron and Chromium, with Pesticides and Pharmaceuticals in contrast, proving inconspicuous.

New *E. coli* contaminations were associated with shallow dug wells that were not sufficiently covered, highlighting a certain aquifer vulnerability.

Yet, contaminations do not only reach the groundwater through wells, but possibly also through the unsaturated zone via groundwater recharge. With such replenishment taking place even under the generally arid climate, this is supported by a number of wells that showed a decrease in TDS.

In the future, the outlined observations call for a number of recommended additional steps:

FUTURE
MONITORING

TRACE ELEMENT
PROJECT

PRECIPITATION
MONITORING

RADON-IN-AIR
MONITORING

GROUNDWATER
RECHARGE ESTIMATIONS

UPDATE OF
GROUNDWATER STATUS MAPS

ENHANCEMENT OF GROUNDWATER
SALINITY MONITORING

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