Lessons learned from trust building activities - GCC countries

Addition to Deliverable 4.3

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Executive Summary

The present document is an addition to the deliverable 4.3 'Lessons learned from trust building activities' and part of the SUBSOL consortium's effort to share intermediate results from the SUBSOL project regarding the development of the prospects for the application of Subsurface Water Solutions (SWS) in different regions globally. It also offers a contribution for a strategy to stimulate international market uptake of SWS.

This document reports about the outcomes of an additional mission to Oman, Bahrain and the United Arab Emirates (UAE), three Arab countries of the Gulf Cooperation Council (GCC) in June 2018.

The particular focus of this addition is a stakeholder identification in the respective countries, the SWS presentation to potential future partners, the identification of potential application sites as well as the collection of basic geographical and institutional information important for the feasibility of SWS. Due to the limited time available for the mission to the three countries, the description of the outcome focusses on the results from one meeting with stakeholders and potential future partners in each of the three countries.

In Oman SUBSOL met under coordination of Sultan Qaboos University (SQU) with national stakeholders. The discussion focused on the greatly favourable situation for the development of ASR options and two parallel tracks of investigations for the storage and recovery of excess desalinated water and of surplus treated sewage effluent in the coastal subsurface, especially in the coastal alluvial aquifers in North and South Batinah regions.

For Bahrain, the Arabian Gulf University (AGU) organized an exchange with national institutions. National interest focuses currently on direct reuse of treated sewage effluent (TSE) especially in irrigation for productive agriculture and landscaping. For potential future excess TSE it is intended to investigate and develop aquifer storage and recovery options primarily in a relatively high transmissivity limestone aquifer.

In the UAE SUBSOL visited the National Water Center (NWC) at the University of the United Arab Emirates (UAEU). Current priorities are focusing on the storage of excess desalinated water primarily in fresh water aquifers. Treated sewage effluent is used mainly for irrigation in landscaping and forests. One area for potential applications of SUBSOL subsurface technologies could be the mitigation of seawater intrusion through pumping of brackish water and simultaneous recharging of coastal aquifers with desalinated water.

All partners in Oman, Bahrain and the UAE as well as SUBSOL partners expressed their interest to develop joint research activities to address storage and recovery of excess desalinated water or treated sewage effluent in coastal aquifers with brackish to saline groundwater.

Introduction

Although not included in the initial project proposal and the description of action, a market scan and capacity building in the Arab region, esp. in selected countries of the Gulf Cooperation Council (GCC) was approved to support the worldwide route to market for the SUBSOL subsurface water solutions (SWS).

In the past five decades, the countries of the Gulf Cooperation Council (Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and UAE) have experienced a rapid socioeconomic development as a result of the global demand for petroleum and natural gas. This development was accompanied by a steep rise in water demand, both due to population growth and industrialization. The overuse of groundwater resources has subsequently led to the depletion of aquifers, the deterioration of groundwater quality, and seawater intrusion. Water scarcity and the availability of energy has fostered the construction of seawater desalination plants which produce approximately 50-90 % of the freshwater supply in the GCC countries[1]. This is associated with a number of disadvantages and risks, among which are the (1) high energy demand leading to high costs and emission of greenhouse gases, (2) downtime of desalination plants due to emergencies such as seawater pollution, natural catastrophes or war, (3) negative impacts on the environment caused by the disposal of the brines.

To ensure water security, the diversification of freshwater sources and the sustainability of the freshwater supply increasingly came into focus of the GCC countries in recent years. Some countries (e.g. Kuwait, Qatar) have conducted feasibility studies or pilot projects for underground storage of freshwater. In 2016, the UAE completed a large-scale ASR system to create a strategic storage of desalinated seawater: The Liwa ASR project in Abu Dhabi for storage of a 90 day emergency supply of 15.5 Mm^3 [2]. The reuse of treated wastewater for non-potable purposes seems to be gaining importance: Urban areas are commonly well equipped with wastewater treatment facilities[3], reclaimed water is already used for municipal landscaping[4]. Furthermore, the research on water quality and reuse schemes is on the rise: The Qatar and Environment & Energy Research Institute (QEERI) increasingly focuses on water quality and reuse.

In addition to water security, food security is an important subject on the agenda of the GCC countries. Relying largely on food imports, political instabilities and risks of crop failures in the food producing countries make the GCC countries particularly vulnerable[5]. Plans to increase local agricultural production are closely linked to the need for providing a safe and sustainable water supply.

[1] Al-Rashed, Akber (2015), Al-Zubari (2017), Klingbeil (2017)
[2] Stuyfzand et al. (2017)
[3] Hamoda (2000)
[4] World Bank (2005)
[5] Shadid, Ahmed (2014)

Within this framework, an initial potential for the application of SWS in the GCC region was identified. A strong need for new water management strategies along with a record of ASR feasibility studies and a generally high technology-readiness appear to be promising pre-requisites for a market scan and capacity building. Three research institutions, which are involved in research on artificial recharge and well linked to the political environment and stakeholders in their respective countries, have already expressed an interest in SWS technologies: The Arabian Gulf University (AGU) in Bahrain, the Sultan Qaboos University (SQU) in Oman and the National Water Center (NWC) at the UAE University. To assess the potential of SWS in these GCC countries, it was agreed to include the GCC region as a potential target region and to carry out research as part of the SUBSOL project.

1. Framework conditions in potential partner countries

In the following the outcome of the meetings with stakeholders and potential future partners in Oman, Bahrain and the UAE is described.

Oman

The Sultanate of Oman is located at the south-eastern side of the Arabian Peninsula. Oman is one of the six members of the GCC. It has an area of c. 310,000 km² and a population of c. 4.7 million (with a population growth of 5.8% annually).

National water situation

Oman's water use amounts to 1,728 Mm³/y[6] of which 84 % are covered by conventional and 16 % by non-conventional resources[7], mainly from desalinated seawater and the reuse of treated wastewater. Compared with the annual renewable water resources of 1,318 Mm³/y[8] the country faces a water deficit of 316 Mm³/y[9]. Average annual rainfall in the Muscat area is about 100 mm/y[10], nationwide even below at 62 mm/y[11] that leads to limited groundwater recharge. In irregular intervals cyclones hit Oman and severe storms and rainfall lead to locally extreme precipitation, storm runoff and flooding of wadis that offer additional water flows that -if intercepted- could provide locally additional water for groundwater recharge[12].

Naturally occurring fresh water is limited to fresh springs, connected aflaj (qanat) systems and largely to groundwater in the coastal plains in North and South Batinah, Salalah region and to a lesser degree in some inland aquifers. Inland groundwater is often of brackish to saline quality. Due to groundwater abstractions above local renewability primarily for agricultural production and esp. along the coastal areas in the North (Al Batinah) and South (Salalah), groundwater levels are declining, and salinization of coastal aquifers occurs.

Awareness

The slow salinization of coastal aquifers has been known since many years. The seawater intrusion in the coastal plains of Al Batinah is monitored since the 1980s with surveys every 5 years. Several research projects have investigated the groundwater quality, i.e. salinity and agricultural uses, as well as potential solutions to address the salinization of groundwater[13].

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6 Al Shibli (2014)
7 Al Abri (2018)
8 Al Abri (2018)
9 Al Shibli (2014)
10 Al Abri (2018)
11 FAO (2009)
12 Howard (2002)
13 Abdalla et al. (2010), Al-Maktoumi et al. (2016), Zekri (2008)

Due to the increasing demand also for drinking water, Oman is producing drinking water today mainly from desalination[14]. Considering the risks associated with the operation of desalination plants especially from algae bloom options are currently developed and investigated for building additional subsurface storage options, i.e. injecting surplus desalinated water into suitable geological subsurface structures and existing aquifers to build artificial groundwater reserves that could be utilized in case of any emergencies.

The reuse of wastewater for landscaping and the irrigation of public green spaces is already practiced[15]. With the increasing capacities of wastewater plants, alternative options are discussed to reuse treated wastewater either directly in agriculture or by artificially recharging suitable aquifers[16].

Local knowledge

Since more than 30 years, Oman has constructed recharge dams (46 as per year 2018 together with many smaller structures (storage dams (#105) in mountains area) to retain a portion of the peak ephemeral flows, thus giving more scope for groundwater recharge[17]. Storm runoff in wadis is intercepted for flood protection and infiltrated to the local alluvial aquifers either upstream of the dam or downstream in specially prepared infiltration zones. The continuous monitoring programmes have demonstrated the freshening up of the groundwater and contributed to a reduction and/or reversal of seawater intrusion. The artificially recharge of groundwater downstream of recharge dams is in some locations intercepted by borehole galleries for emergency water supplies (e.g. if desalination plants may need to reduce their production temporarily).

In the southern region of Salalah Oman has further developed a borehole gallery for injecting treated wastewater from a local wastewater treatment plant to develop a hydraulic barrier and to freshen up groundwater that has been impacted from seawater intrusion in the past.

Institutional capacity

The governmental institutions involved in the development and investigation of Managed Aquifer Recharge options have clear mandates and competent staff that is in the position to assess, investigate and develop economically sound, environmentally acceptable and sustainable solutions to the salinisation of the coastal aquifers. The direct linkage between the ministries, agencies, national organisations or companies and the researchers at Sultan Qaboos University ensures that the advancement of technological solutions is directly accompanied with applied scientific research as needed.

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[14] Ahmed et al. (2001)
[15] Haya Water (2018)
[16] Al-Maktoumi et al. (2017), Zekri et al. (2014)
[17] FAO (2008)

The application of new technologies, such as SWS technologies promoted by SUBSOL may require some additional capacity development in their application and control but it is expected that the institutional capacities in Oman -possibly with some limited assistance from SUBSOL partners- are well developed to handle the assessments of the feasibility as well as the regulatory processes required to implement the setting up of such SWS technologies in the field.

So far Oman has no standard for the quality of water required for the injection into the local aquifers. While a process has already started to address this issue, it might be an option to learn from such regulations developed in other regions such as the EU. This could be addressed through a dedicated training workshop that presents and discusses the relevance of water quality standards for ASR in Oman.

Political environment

Based on recent decisions by the concerned water authority the volumes of water that is lost to the sea, either from treated wastewater or desalination surplus are to be reduced. Hence the political will is clearly present and efforts have been increased to investigate options for reuse of treated wastewater as well as for excess desalinated water to be stored in suitable subsurface structures and used as artificial aquifers and temporal subsurface storage facilities in times of need.

For the utilisation of treated wastewater Oman has set up the national company Haya Water (Oman Wastewater Services Company) and issued a number of Ministerial Decrees (MD) that regulate the permitted chemical and bacteriological compositions for two types direct reuse in landscaping and irrigation (MD 145/1993) as well as for the discharge to the sea (MD 159/2005)[18]. Haya Water activities currently focus on a further increase of direct reuse options for treated wastewater beyond the already practiced applications in landscaping also in the agricultural irrigation.

The use and distribution of the produced desalinated water including the best and most efficient utilisation of excess desalinated water is under the mandate of the Public Authority of Electricity and Water (PAEW / DIAM). Currently feasibility studies are undertaken to investigate the feasibility of Aquifer Storage and Recovery at existing PAEW wellfields that can function as a subsurface storage for excess desalinated water during low demand period while at the same time offer an emergency supply in times of shortage and/or reduced desalination production capacity.

Oman has so far no regulations for the water quality required for injecting either treated wastewater or excess desalinated water into ASR sites. Such regulations will be required to ensure long term sustainability and liability for any potential sites.

[18] Haya Water (2018)

Economic feasibility

Increasing the reuse of treated wastewater in Oman faces challenges such as adequate users that are willing to pay for the treated wastewater, need for additional infrastructure esp. separate pipe networks for treated wastewater, readiness of farmers to utilise treated wastewater on crops, government set tariffs for the utilisation of treated wastewater are below the production cost but still too high for some potential users who have free access to groundwater for irrigation. On the positive side, Haya Water considers the tariff for treated wastewater competitive compared to the fresh water tariff (1 vs. 3 Baisa/Gallon)[19].

For excess desalinated water, first feasibility studies are currently undertaken on behalf of PAEW to find suitable locations for Aquifer Storage and Recovery sites that can function as a subsurface storage while at the same time offer an emergency supply in times of shortage and/or reduced desalination production capacity. All technical options that may be planned for implementation will require additional funds for investments and maintenance and operations that currently cannot be covered through the subsidised drinking water tariffs.

Both directions, the ASR with treated wastewater and/or with excess desalinated water will require thorough multi-dimensional socio-economic studies. These may need to address a number of factors including among others the most feasible locations, taking into account among others hydrogeological setting, recovery potential, existing and potential reduction of salinisation of groundwater, relative location to the production of the injected water (wastewater treatment plants, desalination plants), and distance from potential future users of recovered water from ASR sites.

[19] Haya Water (2018)

Figure 1: SUBSOL meeting with Sultan Qaboos University (SQU), Oman

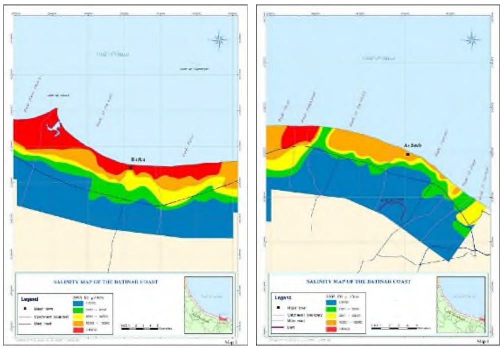

Figure 2: Maps of groundwater salinization in the coastal plain of Al Batinah, Oman[20]

Figure 3: Al Khoud Recharge Dam, Oman, upstream of dam with recharge zone for infiltration of storm water runoff

Figure 4: Al Khoud Recharge Dam, Oman, downstream of dam, recovery / emergency wells for public water supply

Direct stakeholder exchange

Stakeholder	Description
Ministry of Regional Municipalities and Water Resources (MRMWR)	Water resources assessment, management and developments
Ministry of Agriculture and Fisheries (MoAF)	Water irrigation management
Public Authority for Electricity and Water (PAEW / DIAM)	Water production and water supply
Haya Water	Collection, treatment and reuse of treated wastewater
Sultan Qaboos Univeryity (SQU)	Water related research

SWS opportunities

In Oman experiences are still limited with the application of technologies for Managed Aquifer Recharge and Aquifer Storage and Recovery. Only one implementation site exists in Salalah region where treated wastewater is directly injected in the local coastal aquifer to reduce the salinization that has been developed over the years and to build a hydraulic

[20] Al Barwani, Helmi (2006)

barrier to prevent further inflow of seawater in to the coastal aquifer. In case of any challenges with the injection sites, it might be worth discussing with the partners of Oman one of the SWS technologies that would focus on partially penetrating wells in different depths in combination with a managing control software connected to an ongoing monitoring of the salinization in the aquifer.

Considering the total length of the coastal zone of North and South Batinah with its many areas of seawater intrusion due to groundwater over-abstraction there are plenty of potential locations where the application of SWS technologies as promoted by the SUBSOL programme could be feasible. Based on initial feasibility assessments for the locations it is recommended to develop a cooperation with the partners in Oman for a specific research on the potential for application of SWS technologies at pre-feasibility selected sites.

Further options for the application of SWS technologies might be related to inland sites with brackish or saline water in which a fresh water bubble could be injected, monitored and recovered for the local uses.

Beside of specific location focussed studies Oman could benefit from holding joint training workshops with SUBSOL partners to learn from EU experiences for the development of water quality standards for the injection of either excess desalinated water or treated wastewater.

Bahrain

The Kingdom of Bahrain comprises of a group of 40 islands located to the East of the Arabian Peninsula. Bahrain is one of the six members of the GCC. It has an area of c. 750 $km^2$and a population of c. 1.49 million.

National water situation

Historically Bahrain's water supply used to be primarily based on groundwater. The annual precipitation is limited to an average of 83 mm/y[21]. While groundwater levels dropped due to over-abstraction and urban development increased, today's drinking water supply is largely based on desalination from seawater and brackish groundwater.

Bahrain as an island forms a dome structure connected to the Dammam aquifer and - below - to the Rus - Umm Er Radhuma (UER) formation; both extending from the mainland of the Arabian Peninsula to Bahrain. The Dammam aquifer is the only natural "renewable" water source in Bahrain. It is part of an extensive regional aquifer (the Eastern Arabian aquifer), recharged by underflow (100 Mm^3/y prior to development). It comprises of two units; in Bahrain called Alat member (Aquifer A) and Khobar member (B). The below Rus-UER aquifer system (C) is considered non-renewable and a lens of limited areal extent with higher salinities of 5,000-25,000 mg/l[22].

The Dammam aquifer used to discharge in Bahrain from multiple surface and submarine springs. With the beginning of the groundwater abstractions and developments since 1920 the spring discharge dropped until it ceased around 1990. The natural renewability of the aquifer has been estimated to be around 112 Mm^3/y. Already 1970 the groundwater abstractions were higher than this "safe yield" and peaked before 2000 at 250 Mm^3/y. Today abstractions from Dammam aquifer are around 100 Mm^3/y[23]. With the reduction and later disappearance of the springs, groundwater levels fell in both aquifers A and B. Since c. 2000 the water levels in both aquifers dropped below sea level; risking increasing deterioration of groundwater quality due to seawater intrusion. With the substantial reduction of abstractions after 2000 - also due to a reduction of agricultural production - the groundwater levels started to recover but still until recently the levels are slightly below sea level.

Today's drinking water in Bahrain is based primarily on desalination. The discharge of water from households and industries led to high volumes of wastewater that are transferred to wastewater treatment plants such as the Water Pollution Control Centre (WPCC) in Tubli[24]. Tubli is currently the largest wastewater treatment plan with a total capacity of 200,000 m^3/d. However the actual inflow into often amounts to 300,000 m^3/d. The plant produces an output of 150,000 m^3/d treated sewage effluent. Only a small

[21] FAO (2008)
[22] Zubari (2018), Zubari (1999)
[23] Zubari (2018)
[24] MoW (2011)

volume of treated wastewater is reused through direct applications in agriculture. The remaining is treated - but discharged to the sea. The capacities to increase the direct reuse of wastewater are limited. To benefit more from the remaining large volumes of treated wastewater it was proposed to use the excess through Aquifer Storage and Recovery and develop a subsurface storage that on one side reduces the progressing seawater intrusion as well as being available as an additional source of water for agricultural production. Currently the feasibility of various ASR options are investigated.

ASR has been discussed also as a solution and temporary storage to be used for seasonal excess water produced by the desalination plans as well as storm water runoff[25].

Awareness

The governmental institutions in Bahrain are aware of the national water situation, including the increasing salinity in the aquifers of the Dammam formation as well as the large volumes of wastewater that requires treatment and offer an additional water source that is currently still underutilised.

To improve the national coordination of water-related issues that are addressed by a number of different ministries and government institutions a National Water Council (NWC) with a technical committee has been set up. The NWC provides the framework for an enabling environment that is expected to address the water sector challenges in a more holistic and integrated manner.

Additionally the combination of formerly separate governmental offices for water resources management, agricultural development and the treatment and reuse of wastewater under the recently set up Ministry of Works, Municipalities and Urban Planning (MWMUP) is expected to contribute to a better coordination of water sector activities in the future.

Local knowledge

Since 1989 research has been addressing the local groundwater situation and options for recharging the aquifers. Beside of research activities from the respective ministries and governmental institutions, the Arabian Gulf University (AGU) has been working on national and GCC-research cooperation in the water sector since many years. The AGU is a GCC-funded university that is hosted by Bahrain.

For the injection of treated wastewater four sites were studies in more detail. Currently these sites are undergoing detailed drilling and testing. It is expected that this will lead to the selection of one pilot site in the Muharrak area with the aquifer B as the preferred target horizon for the injection, alternatively aquifer C. While such a pilot location can be understood from the perspective where the large volumes of treated wastewater are available, the actual major agricultural areas are located in the Northwest of Bahrain. The

[25] Naik et al. (2017)

priority target horizon, aquifer B consists of two distinct layrs of which the upper 5-15 m show a highly fractured section that is expected to draw in most of the injected water. At the pilot site in Muharrak it is expected that at a depth of 50-60 m the groundwater is impacted by seawater intrusion.

Institutional capacity

The capacity at the national level is linked to the individual ministries, governmental institutions, and their respective mandates. While some governmental institutions have been joined lately, the processes are still often narrowly related to individual sub-sector aspects. The solutions in a small island state like Bahrain require more holistic and integrated solutions that are expected to be forthcoming through the coordination role of the National Water Council and its committees.

Political environment

The National Water Council (NWC) has been re-initialised recently. The NWC is a higher inter-ministerial committee for national coordination of water issues between the relevant ministries. It includes an NWC technical committee. With the coordination mandate, the NWC offers an adequate mechanism to discuss and agree over important national water issues. In the same context the combination of formerly separate ministries for water resources, agriculture and the treatment and reuse of wastewater under one roof offers the potential for better coordinated work in the water sector.

Challenges for the application of ASR technologies such as SWS remain as until now Bahrain lags specific regulations for the injection of treated wastewater (or other sources of water) into aquifers.

Economic feasibility

A number of initiatives have been taken in Bahrain to discuss the economic feasibility of ASR applications for different location scenarios. The economic feasibility of the selected sites depends on many different aspects and need to include the cost comparison between different alternative options.

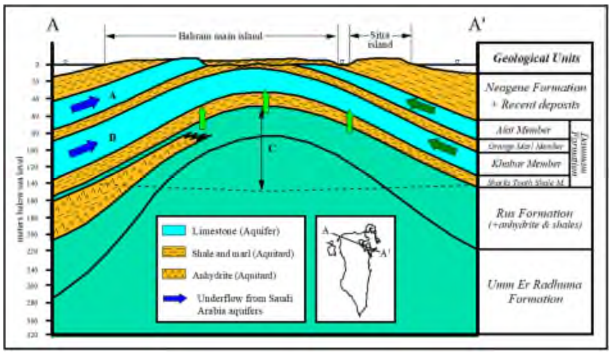

Figure 5: Hydrogeological West-East cross-section of Bahrain with three aquifers: A - Alat member, Dammam formation, B -Khobar member, Dammam formation, C – Rus-UER aquifer system[26]

Figure 6: Outcrop of Khobar member, Dammam formation, Bahrain © W. Zubari, AGU, Bahrain

Figure 7: Water Pollution Control Centre (WPCC), Tubli, Bahrain

Direct stakeholder exchange

Stakeholder	Description
National Water Council (NWC), Technical Committee	Coordination of Water Sector Activities
Ministry of Works, Municipalities and Urban Planning (MWMUP), Sanitary Engineering Planning & Projects Directorate (SEPPD)	Management and Regulation of the Collection, Treatment and Reuse of Treated of Wastewater
Ministry of Works, Municipalities and Urban Planning (MWMUP), Directorate of Agricultural Engineering and Water Resources	Management of Water Resources and Agricultural Water Uses
Arabian Gulf University (AGU)	Water related research

SWS opportunities

Aquifer Storage and Recovery as a tool for groundwater storage enhancement using surplus tertiary TSE is a viable option for Bahrain especially at a certain location in western

[26] Zubari (2018)

Bahrain, where maximum “hydraulic benefits” and minimum “health risks” are found. The application of ASR could contribute to a recovering of water levels and a reduction of salinity. However, associated health risks and overall economic cost-benefit assessments need to be conducted, as well as detailed feasibility studies for the adequate ASR technology to be applied, before the implementation of such a scheme.

Since the potential locations for injections are located close to the sea and seawater has intruded into the aquifers the SUBSOL / SWS technology with their specific experiences in controlling saline water intrusions have a good potential to be suitable for the given circumstances.

United Arab Emirates (UAE)

The United Arab Emirates are located on the eastern side of the Arabian Peninsula. The UAE is a federation of seven individual emirates from which Abu Dhabi emirate is the largest by area (approx. 80 % of the total area of the UAE). The UAE is one of the six members of the GCC. It has an area of c. 84.000 km^2 and a population of c. 9.27 million.

National water situation

Average annual rainfall is 78 mm, with lowest levels of less than 40 mm around Liwa in the southern desert and highest at 160 mm in the northeastern mountains[27]. Naturally, renewable fresh groundwater resources in the UAE are limited primarily to some aquifers in the northern Emirates and to the Al Ain area. Other fresh groundwater resources are mostly considered non-renewable. The latter is often connected to the larger aquifer systems of the Arabian peninsula. With the increasing urban development in the UAE the drinking water supply has shifted to desalination of seawater. Groundwater has, however been used for agriculture and other local developments.

Due to groundwater abstractions above the renewability and changes in the rainfall distribution groundwater levels dropped over time and saline water intruded into the coastal aquifers from the sea as well as some inland aquifers[28]. The UAE started early to investigate remedial measures and implement projects to enhance groundwater storage through infiltration dams in the more mountainous regions in the northern Emirates as well as the development of strategic subsurface groundwater storage with excess water from desalination plants such as Nizwa, Sharjah and Liwa, Abu Dhabi[29].

Treated wastewater (TSE) is currently mainly used for landscaping and forests.

Awareness

The change in groundwater conditions was monitored early and remedial measures taken. The UAE started early to investigate[30] and implement projects to enhance groundwater storage through infiltration dams in the more mountainous regions in the northern Emirates as well as the development of strategic subsurface groundwater storage with excess water from desalination plants such as Nizwa, Sharjah and Liwa, Abu Dhabi.

Local knowledge

Beside of a number of federal and Emirate level ministries and government instituions, as well as water related think tanks, the National Water Center at the United Arab Emirates University (UAEU) in Al Ain has been set up in 2011 to address research issues of national relevance. The NWC brings together a number of core staff and water scientists and staff

[27] FAO (2008)
[28] Brook, Dawoud (2005), Sherif (2018)
[29] Hutchinson (1998), Mohamed, Al-Qaran (2015), Sathish, Mohamed (2018), Sherif, Shetty (2017)
[30] Sherif, Hamza (2001)

from different faculties in the UAEU in an integrated approach. It connects to an international water consortium of regional and international water scientists from abroad.

The NWC has excellent links to the governmental institutions in the UAE and conducts a number of strategic research projects for the UAE as well as for other countries in the region. Currently the NWC runs 14 projects some of which addressing research on aquifer storage and recovery. Through the inter-disciplinary team available at the NWC and UAEU the institution offers excellent partnership options to cooperate for research on the feasibility of Subsurface Water Solutions (SWS) in the UAE.

Institutional capacity

The NWC through own staff and in cooperation with the research institutes of UAEU as well as through many international partnerships has a lot of experience in the research on Aquifer Storage and Recovery options, from monitoring of infiltration dams that encourage groundwater recharge from storm water to the monitoring of the infection of desalinated seawater through well fields.

With the governmental institutions in the Emirate of Abu Dhabi, such as the Environment Agency Abu Dhabi as well as the respective ministries at the federal level, the UAE offer a well-established institutional environment that has been working on a number of ASR projects over the last years and thus can provide the necessary enabling environment to ensure successful outcomes of research cooperation projects.

Political environment

The UAE is characterised by a federal level and institutions that are directly related to the individual emirates. Currently the national interest has been focussed on enhancing naturally fresh groundwater with additional fresh water through the development of emergency groundwater storage from excess desalinated water as well as the enhancement of groundwater recharge through infiltration dams. One of the largest ASR sites for strategic groundwater storage has been developed in Liwa, Abu Dhabi[31].

Treated wastewater is primarily directly reused in landscaping and forests. There are no plans to inject or infiltrate TSE into fresh water aquifers. However, in some coastal zones well-treated wastewater might at some stage be considered as a suitable resource to enhance groundwater recharge and prevent or reduce seawater intrusion into the coastal aquifers.

[31] Stuyfzand et al. (2017)

Economic feasibility

The economic feasibility assessments have been addressed during investigations of alternative options for enhancing the groundwater storage[32]. In some cases, if the ASR systems are considered for emergency supplies, this also has to be taken into account within such assessments.

Figure 8: SUBSOL meeting with National Water Center (NWC), Al Ain, UAE

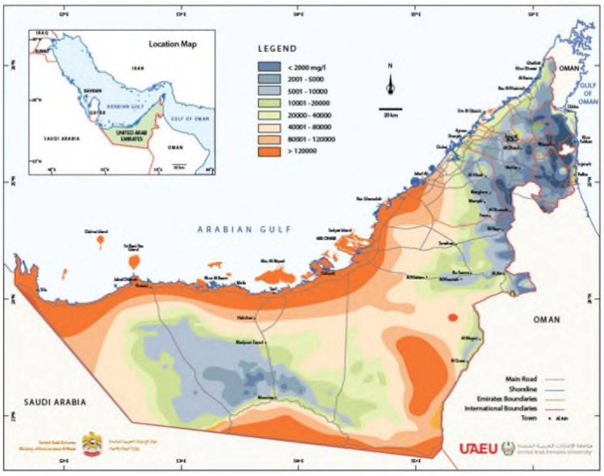

Figure 9: Map of Groundwater Salinity in the UAE, 2012[33]

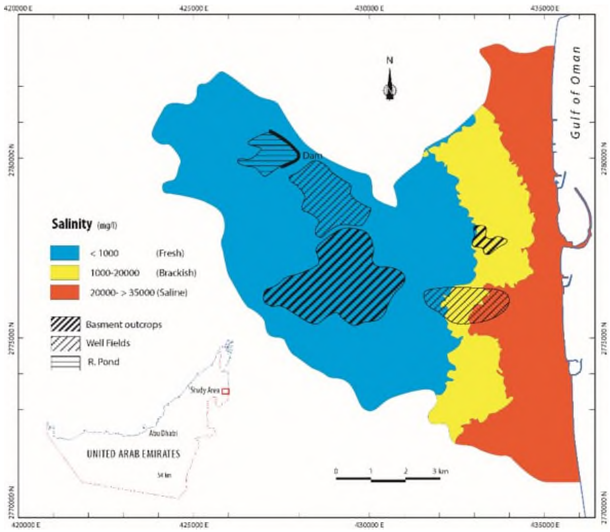

Figure 10: Map of Groundwater Salinity in Fujeirah, UAE[34]

Direct stakeholder exchange

Stakeholder	Description
National Water Center (NWC) at United Arab Emirates University (UAEU)	Water related research

[32] Dawoud (2017)
[33] Sherif (2018)
[34] Sherif (2018)

SWS opportunities

Beside of the already well established activities in the UAE for the storage of desalinated water in fresh groundwater / aquifers and the enhancement of groundwater recharge through infiltration dams, SWS technologies might be suitable tools to support the UAE in efforts to limit or reduce seawater intrusion in coastal areas through the injection of excess desalinated water or treated wastewater. Further detailed assessments would be needed to assess the applicability in the given local environments. Based on the excellent scientific framework conditions at the NWC and in the UAE the potential for successful research cooperation is considered good.

2. Conclusion

During the visit to Oman, Bahrain and the UAE the SUBSOL team had the opportunity to meet with relevant stakeholders involved in the discussion and development of ASR applications at the respective national level. Based on the meetings with the stakeholders the team was able to develop a first assessment of the water challenges faced in each country, the technological approaches discussed, planned or already implemented, the framework conditions with regard to the national capacities to address the respective challenges as well as the socio-economic and political environment. Overall all three countries and potential partners showed a great interest in a closer cooperation with EU partners of the SUBSOL project for the further assessment of the applicability and feasibility of SWS technologies and related capacity development activities in their respective national context.

The SUBSOL team that undertook the mission came to the conclusion that overall conditions for a cooperation with Oman, Bahrain and the UAE offer great opportunities for further research cooperation between EU and GCC partners that shall contribute to a better market access of EU-developed technologies such as SWS technologies in the GCC region.

The meetings in Oman focused on the development of ASR options and two parallel tracks of investigations for the storage and recovery of excess desalinated water and of surplus treated sewage effluent in the coastal subsurface, especially in the coastal alluvial aquifers in North and South Batinah regions. SWS technologies are well suited for coastal zones and for the stabilisation or mitigation of saline water intrusions. As such there is a good potential for application which would need to be assessed further.

In Bahrain the exchange with national institutions addressed the current focus on direct reuse of treated sewage effluent (TSE) especially in irrigation for productive agriculture and landscaping. The meeting discussed further the use of future excess TSE for ASR options primarily in a relatively high transmissivity limestone aquifer and related ongoing feasibility assessments. The suitability of SWS technologies might be a possible option in the context of the expected salinities in the groundwater and would require further detailed assessments of the feasibility of this technology in the given hydrogeological environment.

In the UAE current priorities focus on the storage of excess desalinated water primarily in fresh water aquifers among others for emergency situations. Treated sewage effluent is used mainly for irrigation in landscaping and forests. SWS technologies could contribute to the mitigation of seawater intrusion through pumping of brackish water and simultaneous recharging of coastal aquifers with desalinated water.

All partners in Oman, Bahrain and the UAE as well as SUBSOL partners expressed their interest to develop joint research activities to address storage and recovery of excess desalinated water or treated sewage effluent in aquifers with brackish to saline groundwater.

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