Investigation of Shallow Water Table Rise at Sultan Qaboos University Campus

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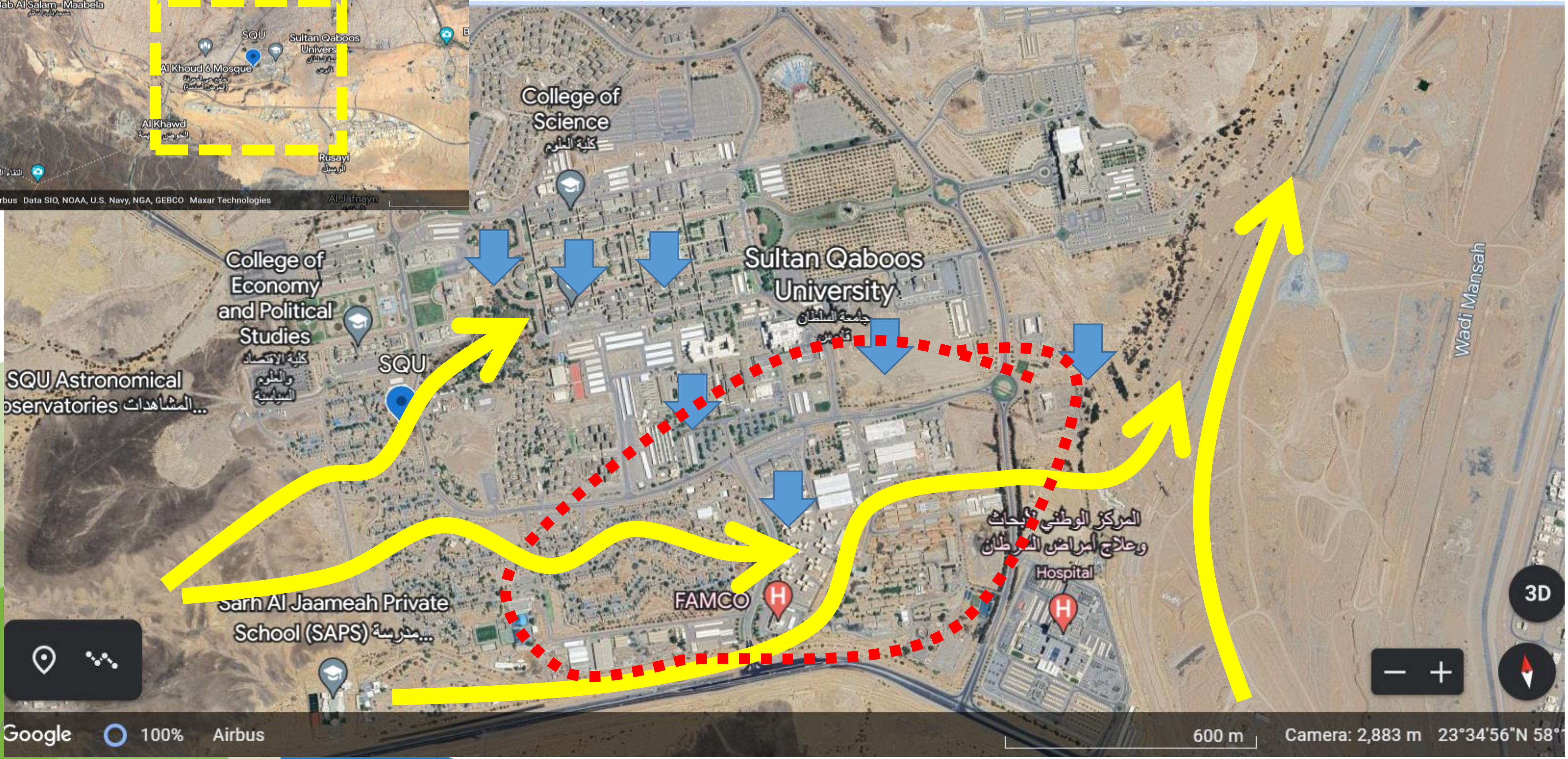
Overview of Shallow Water Table problem

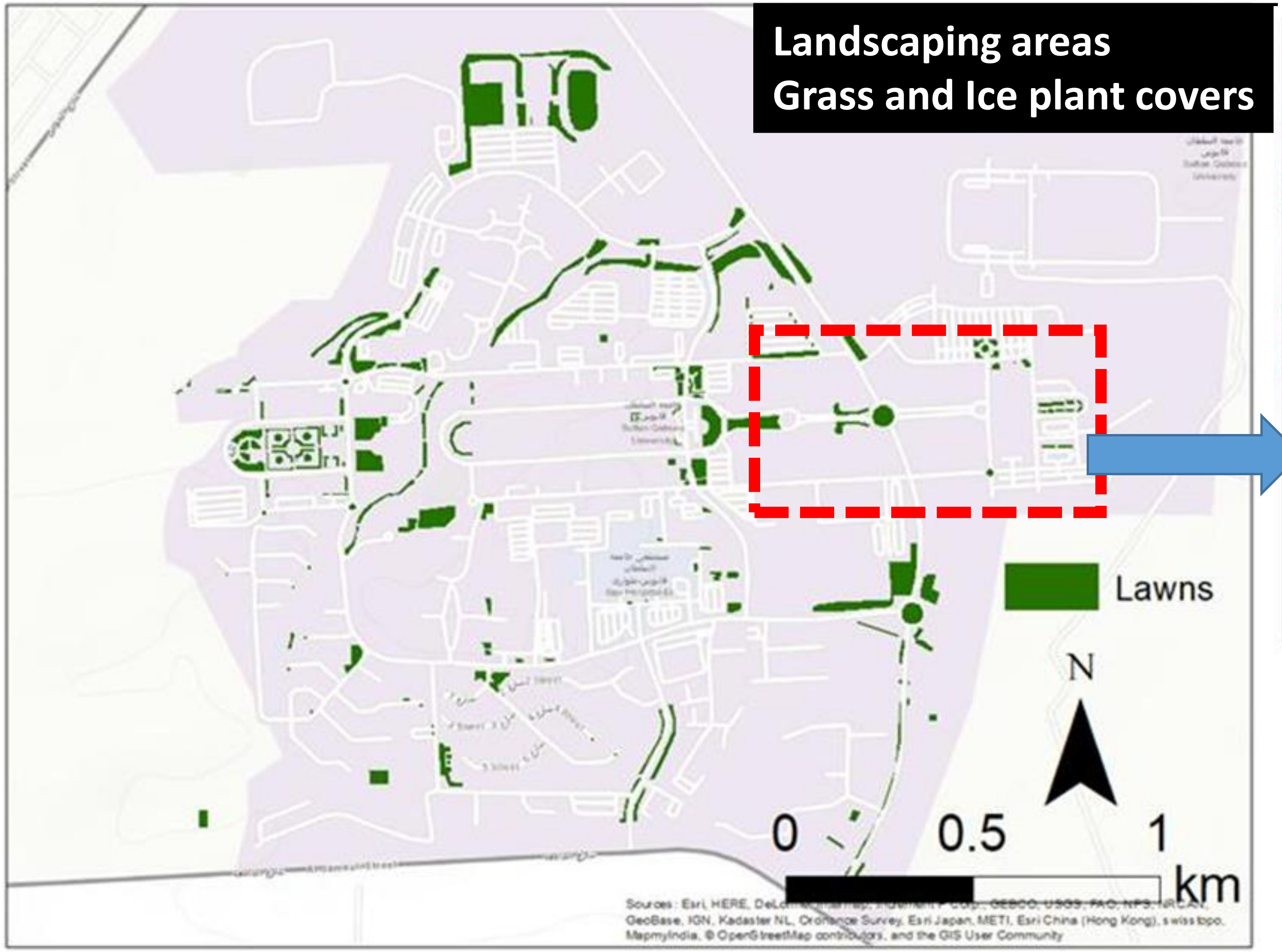
- Recently, a shallow water table (SWT) has emerged in several cities of the arid to semi-arid region of the Arabian Gulf Cooperation Council (GCC) countries that threaten the urban infrastructure (differential settlement and cracking of waterlogged buildings, rutting, structural weakening, and damage to the city roads), public health, ecohydrology of city parks and gardens, among others.
- Several factors, e.g. a **fast urban development in major cities**, **complex subsurface geology**, **leaks from various types of water networks**, and **inefficient surface/subsurface drainage** of natural water may result in the formation of shallow perched aquifer systems in urban areas.

Shallow Water Table problem at Sultan Qaboos University

Spots of detected shallow water table



Shallow Water Table problem at Sultan Qaboos University: landscaping across SQU



The density of plants in selected area at SQU

SQU Campus – landscaping and plantation

Sl No	Types of plants	Total QTY of Plants before removal	Total Plants removed	Actual QTY of plants after removal	% removal
1	Trees Nos.	9813	753	9060	7.67%
2	Ornamental Palms in Nos	499	18	481	3.61%
3	Shrubs in Nos	17763	4607	13156	25.94%
4	Dwarf Shrubs in Nos	6099	2471	3628	40.51%
5	Ground Cover in M2	87412	77075	10337	88.17%
6	Seasonal in M2	5258	1142	4116	21.72%
7	Hedges in RM	10318	360	9958	3.49%
8	Date Palm In Nos	2089		2089	0.00%
9	Grass in M2	67902	1427	66475	2.10%
10	Succulents in Nos	1289	57	1232	4.42%
11	Creeper in Nos	119	13	106	10.92%

- Total # of plants: "trees, palms, shrubs, succulent creeper,…", in total 37,671 (over 6.5 km^2 campus)
- Grass and ice plant groundcover: 160,572 m^2 along with 10318 running meters of Hedges)

Water at SQU
Volume and source of the water

Potable water supply:

Desalinated water: 989,326 **m^3 annually**

Source of irrigation water (in year 2021 – before the study):

1. **1,023,783 m^3 annually:**
   - **82% Treated wastewater**
   - **18% desalinated water**

Water leaks from all water supply networks in the year 2021:

190 reported leak incidence

Unfortunately, no records of leaked volumes

Main Objectives and Approach of the Study

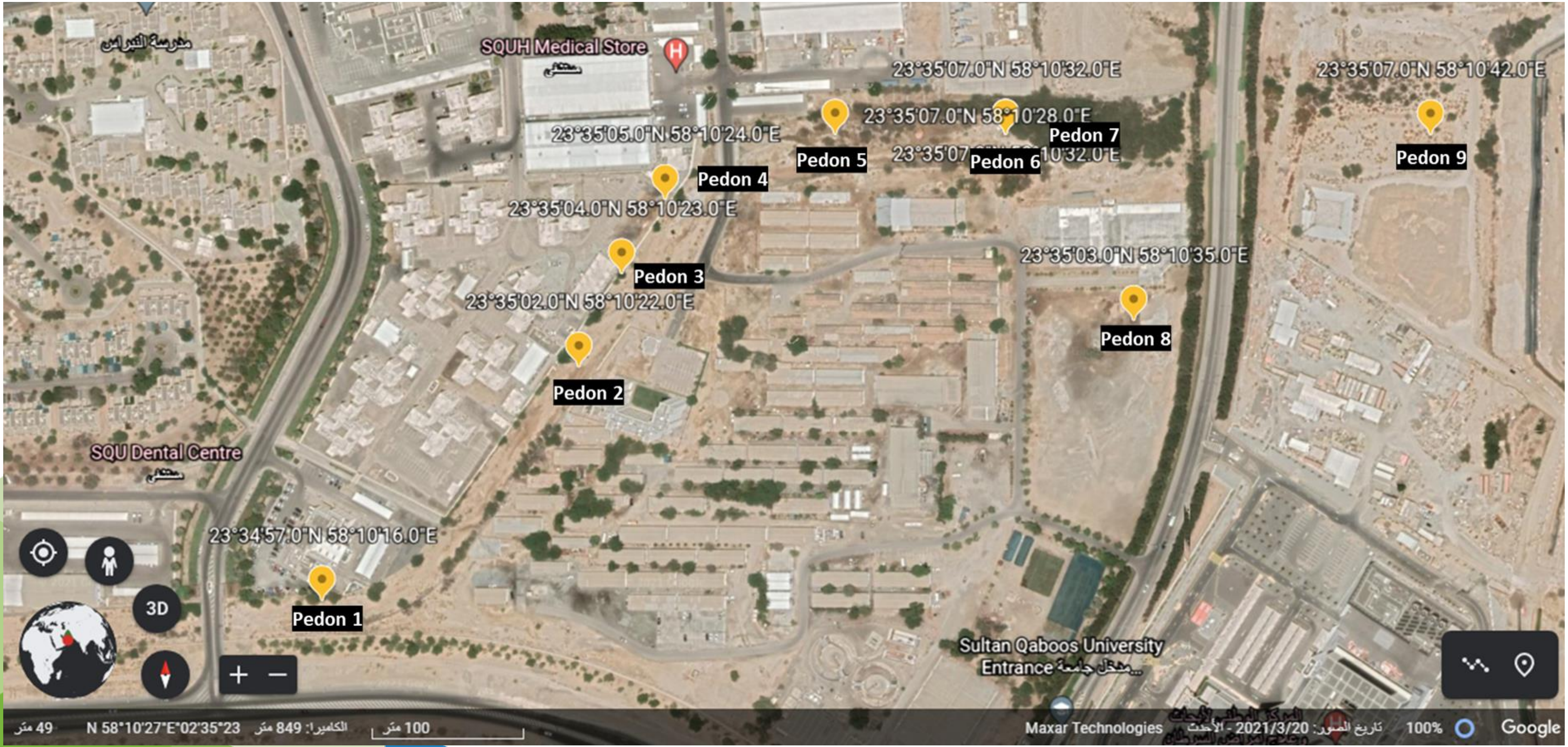
The main objective of the project: is to identify the source of the shallow water and factors for the formation of perched shallow water table and proposed solutions at SQU campus

The methodology includes:

- Pedological investigation: soil layering, soil's properties and heir evolution, etc.
- Water chemistry
- Geophysical survey investigation
- Catchment hydrology
- Numerical modeling using both Hydrus and MODFLOW Pro codes

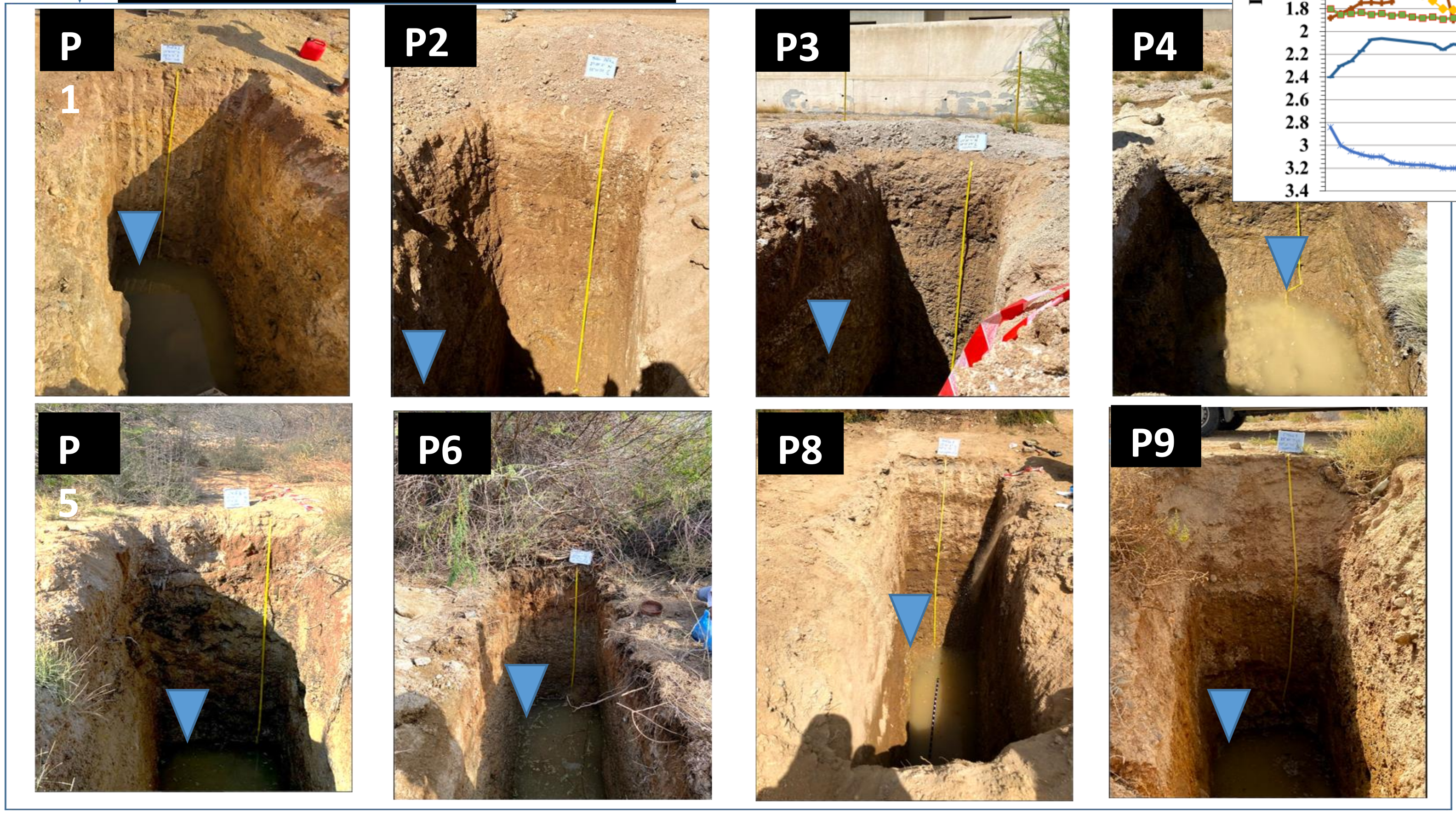
Shallow Water table at Sultan Qaboos University

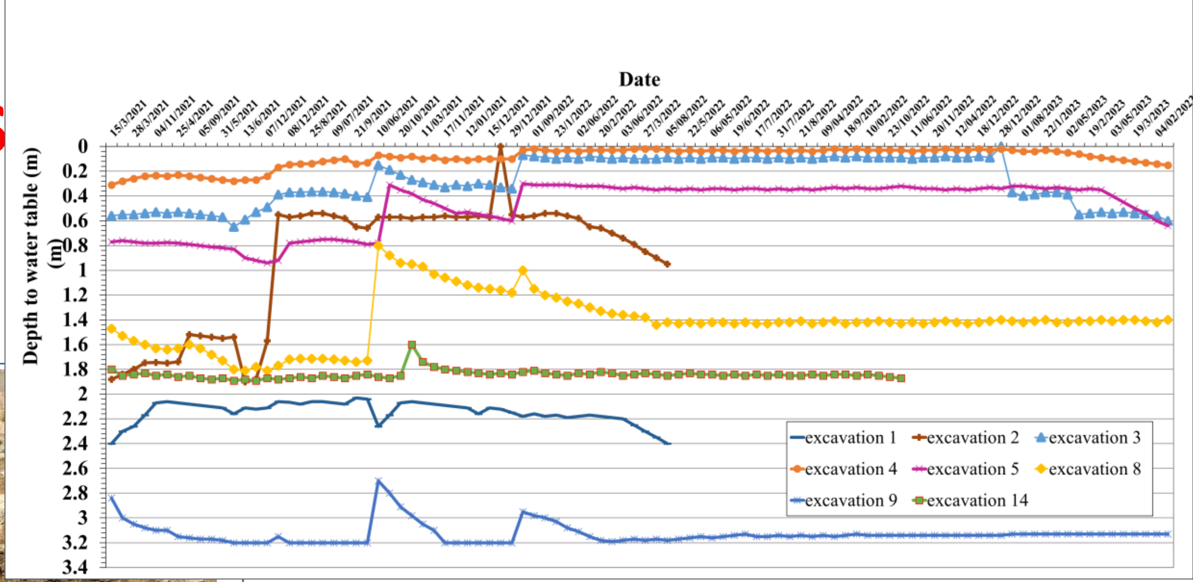
Excavated trenches and pits



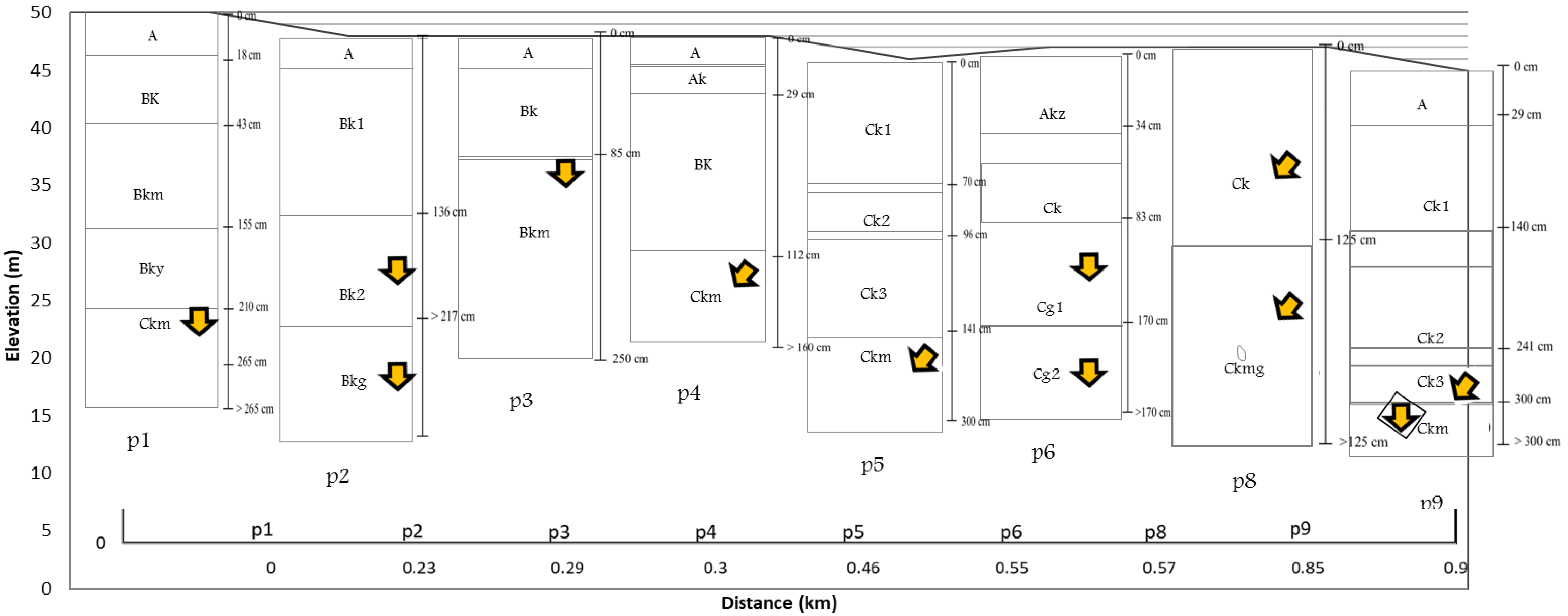
Studied Soil Pedons – water levels

The water table



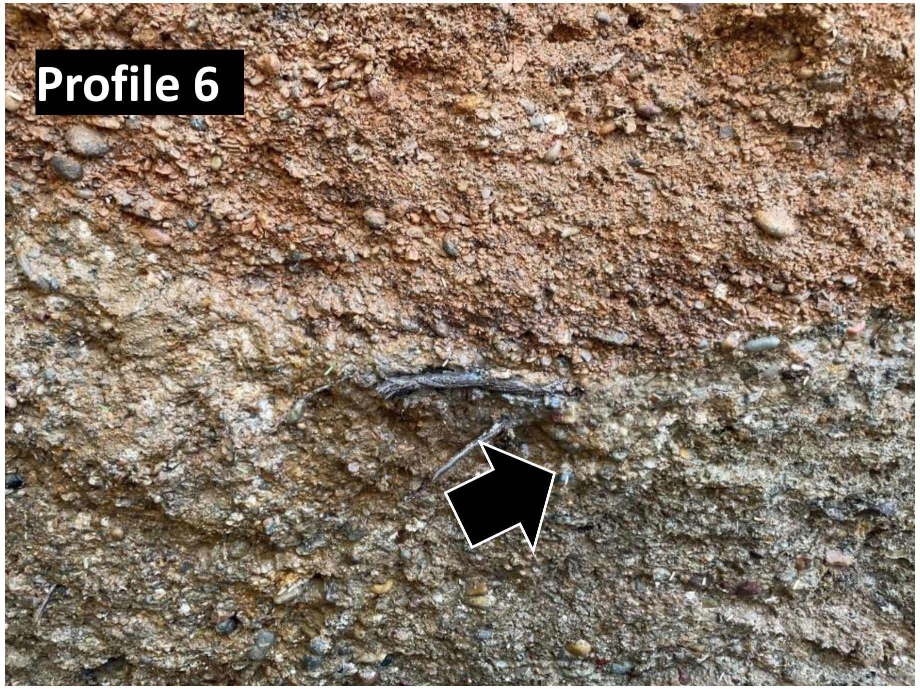


Soil Profiles Horizons and Zones of Detected Water Seepage



Zone of detected groundwater seepage into the soil profile

Highly permeable strata (laminate) act as conduits for infiltrating water

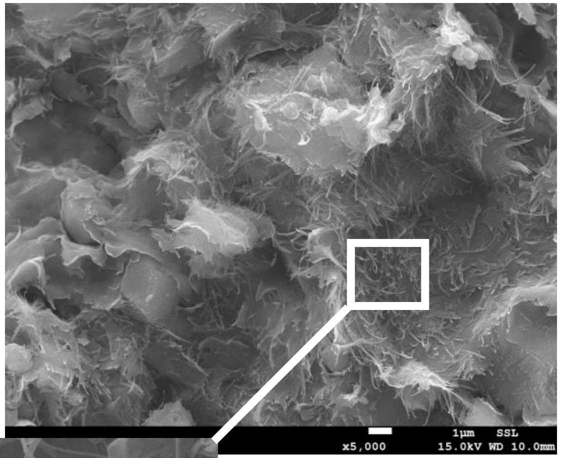


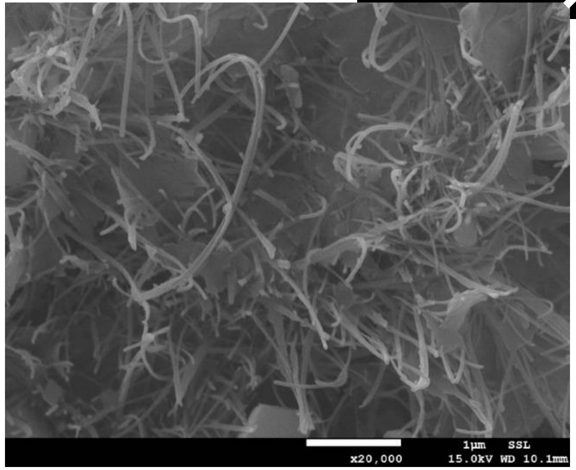
Soil **Gleying** indicates prolonged waterlogging

Soil Mineralogical Analyses

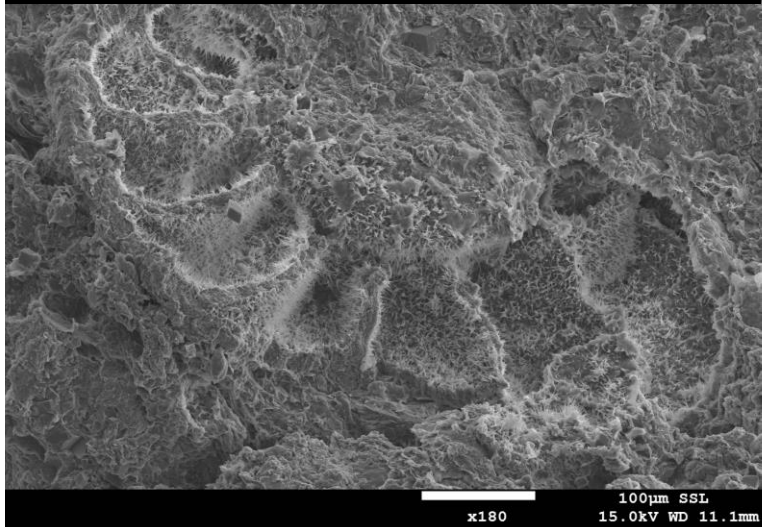
- Soil conditions under rising groundwater, high ECe, and calcium carbonate are likely to trigger *in situ* pedogenic formation of palygorskite (Neaman and Singer, 2004; *Hojati and Khademi, 2011; Shahrokh et al., 2018*)
- Palygorskite has more potential towards disaggregation and translocation in soils (*Neaman and Singer, 2004*)

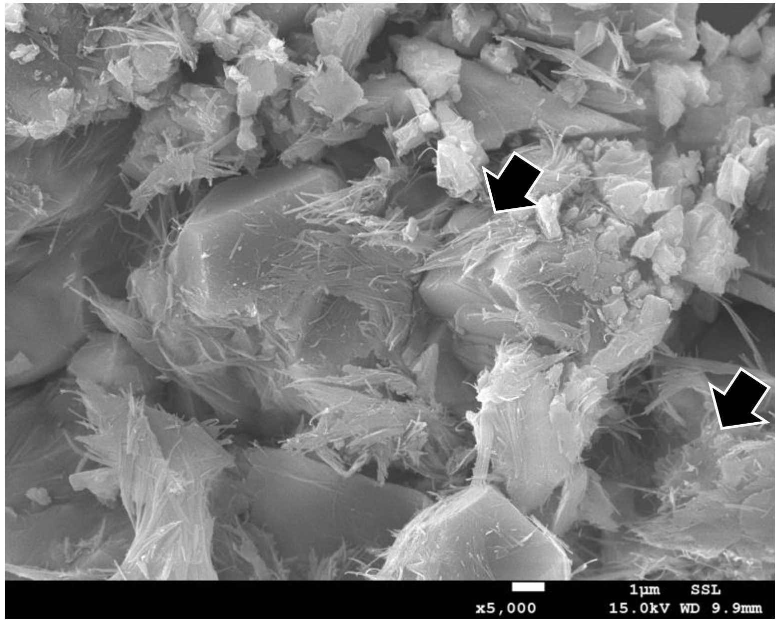
Palygorskite fibers grown among carbonate crystals





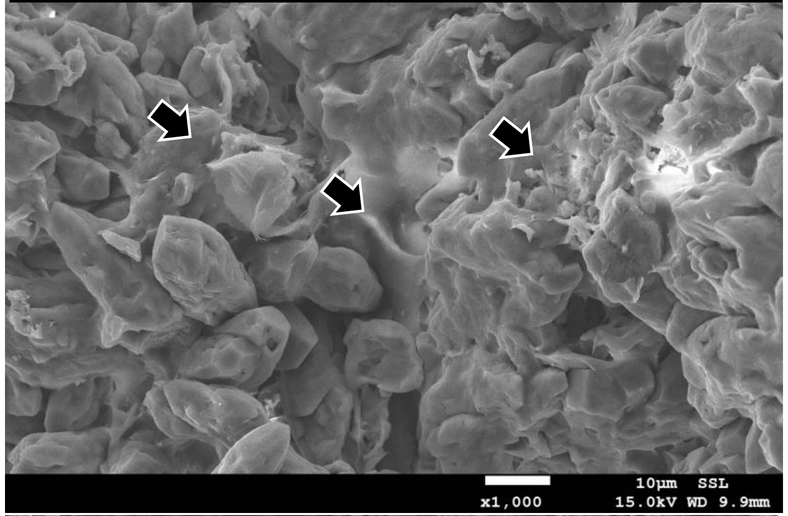
Cementation via calcification

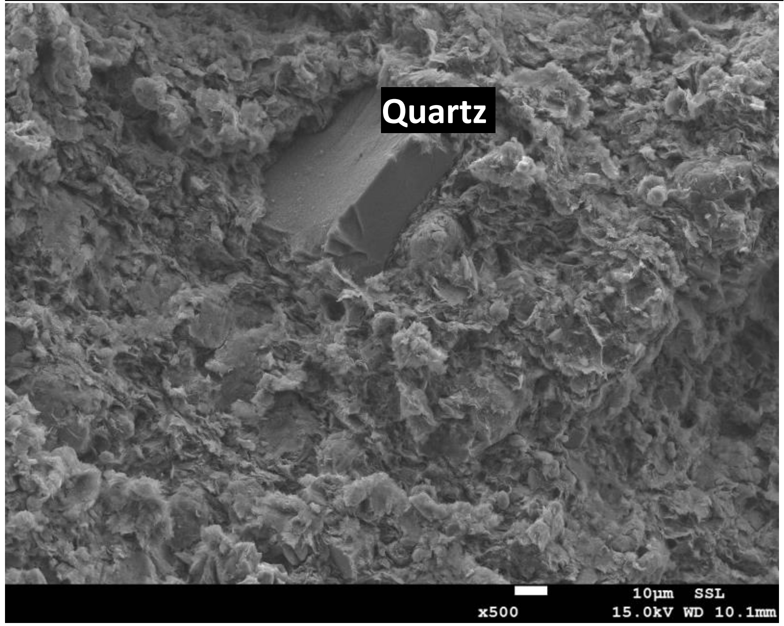




Incipient cementation of soil grains by calcic materials

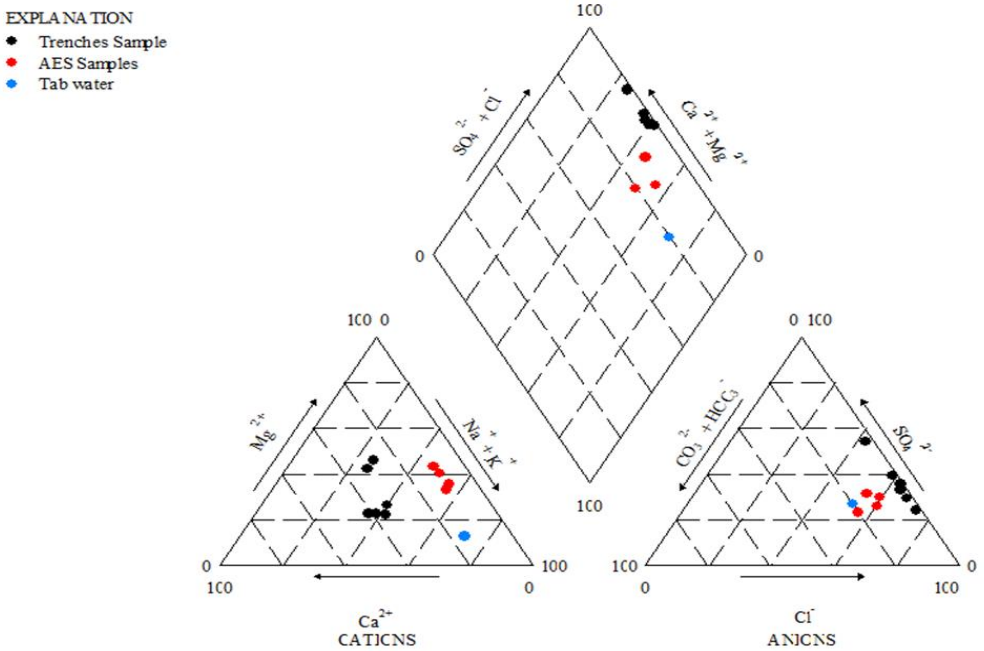
Subangular edges and corners indicate evidence of calcic dissolution (Profile 4).

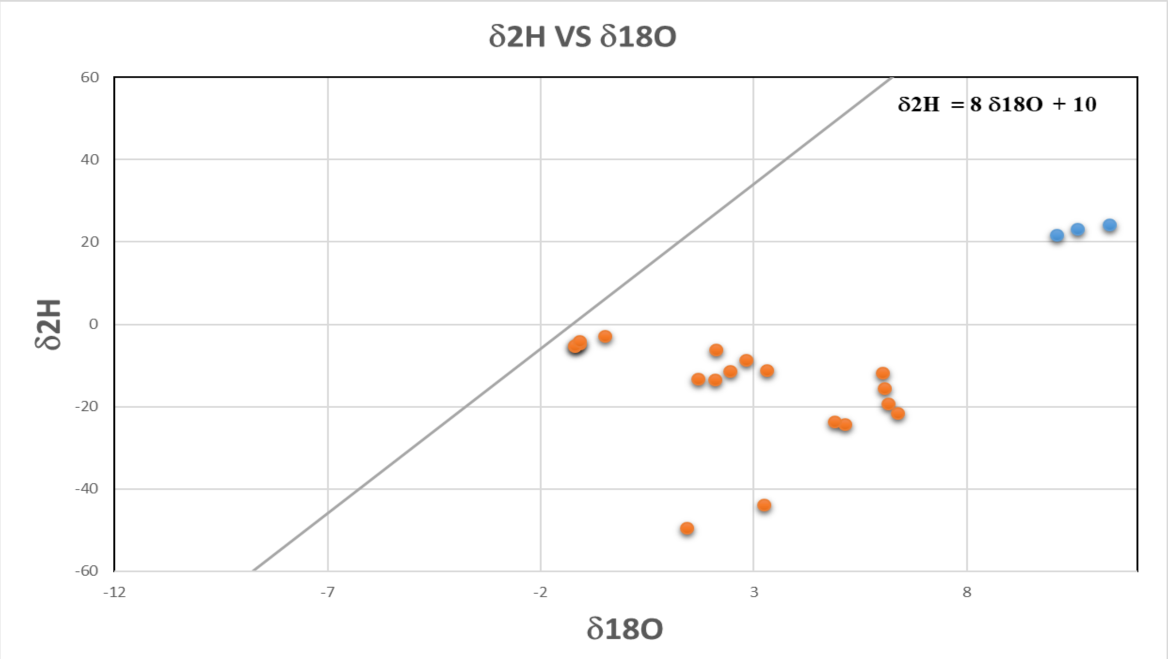




Quartz surrounded by dense soil fabric (Profile 9)

Analysis of Water Chemistry and Isotopes



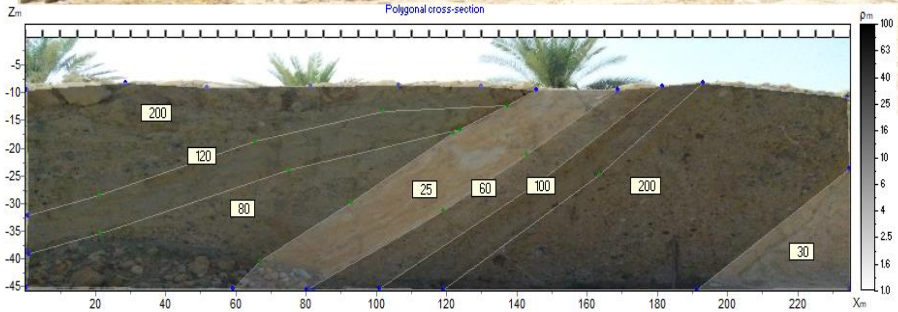


The fall of the samples around the 0 values of deuterium and oxygen-18 is an indicative of the source from the tap desalinated water. However, isotopic enriched values falling to the right from the GMWL indicates the effect of strong evaporation from shallow depth or at surface. The rainfall water collected during the precipitation period in January 2021 clearly manifests the atmospheric evaporation and the samples fall on the top right corner of the diagram indicating extreme enrichment. On the contrary, groundwater samples analyzed in previous studies (e.g. Abdalla 2016 a and b) have shown depleted isotopic signature which is attributed to their formation during wetter humid climates different than today's climate. **Therefore, mixing of current rainfall, relatively older groundwater and tap desalinated water under the effect of evaporation will result in an isotopic signature reflecting the fingerprints of all water sources as shown in the right Fig. above.** It is obvious from the diagram that seasonal variations in the analytical values are observed and these variations are mainly driven by evaporation and mixing processes.

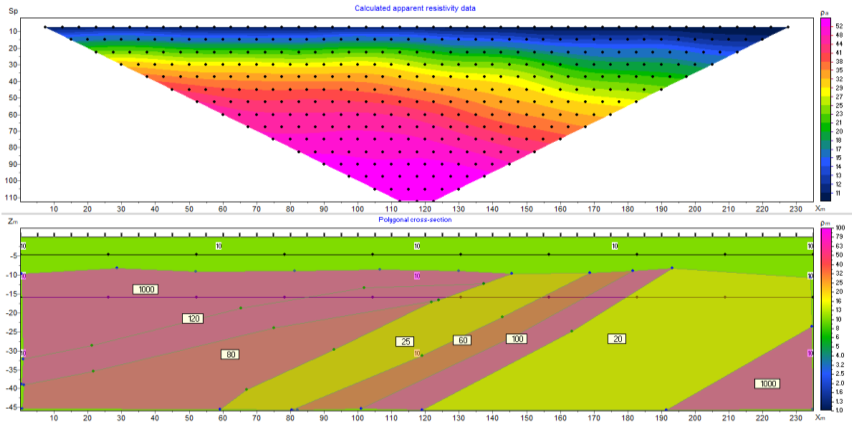
Geophysical Survey

A satellite image showing a number of profiles acquired over the study area

A photo taken from SQU campus showing exposed layers

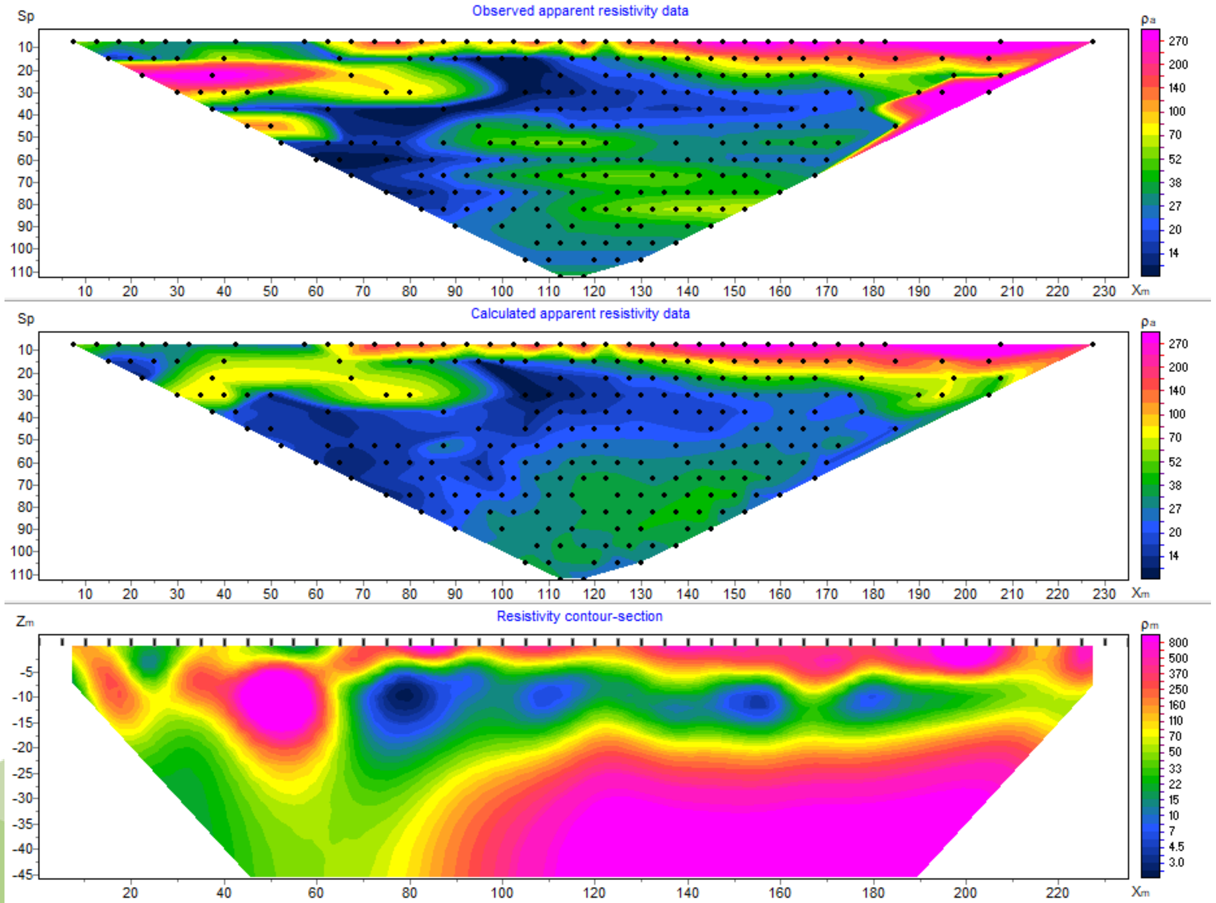


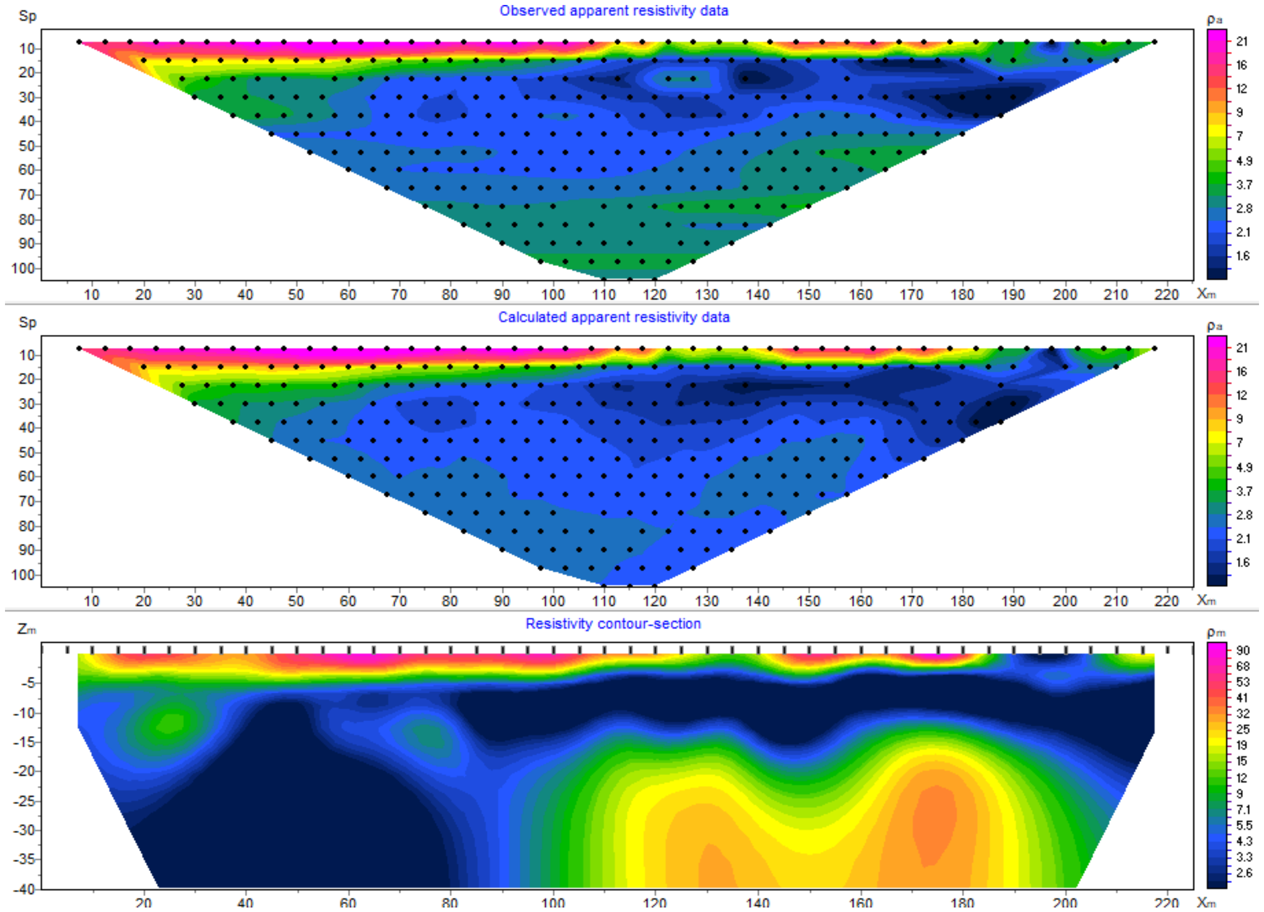
Layers are assigned different resistivity values



Resistivity model (bottom) and its associated forward model (top). The Forward model represents the observed resistivity data that can be collected from the field.

Geophysical Survey



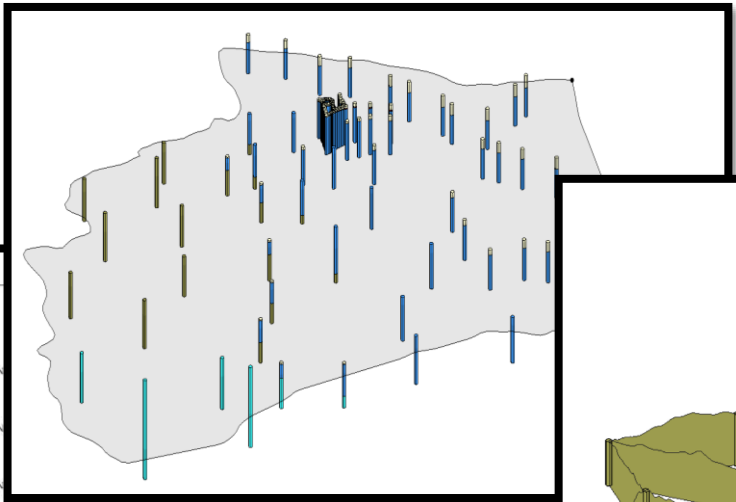


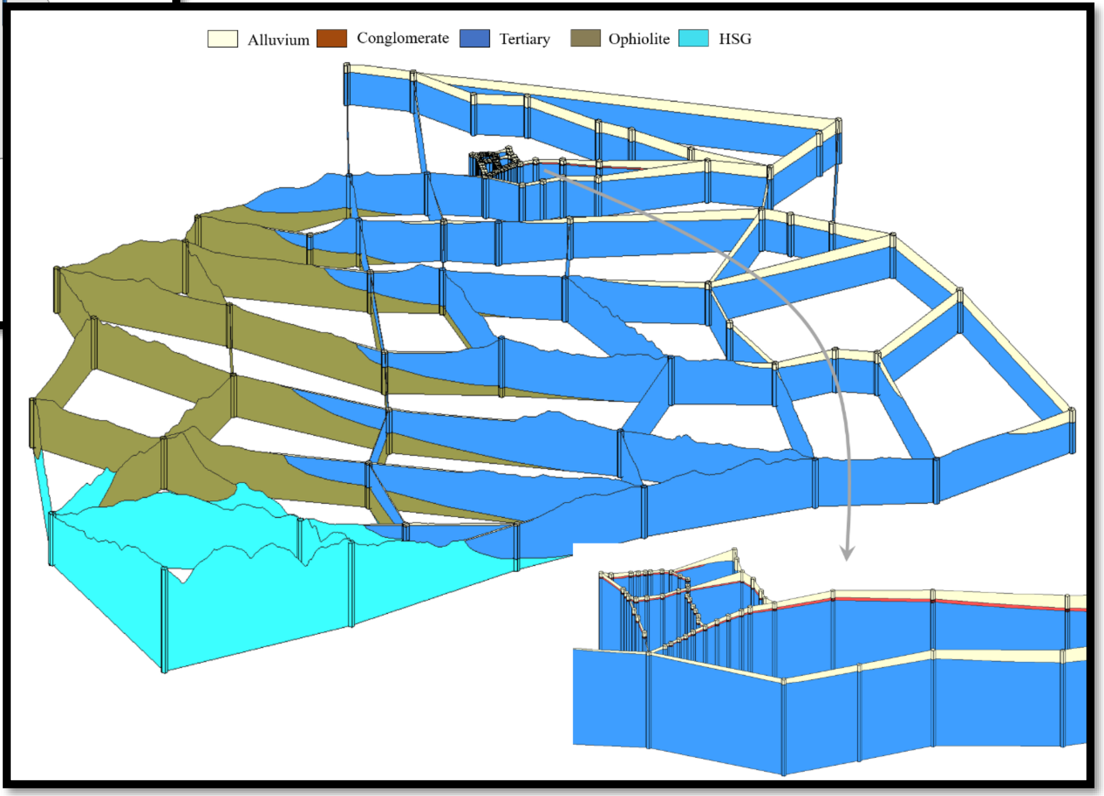
Resistivity section from the inversion of Profile 01. Note that along the same line, the water content varies laterally and vertically.

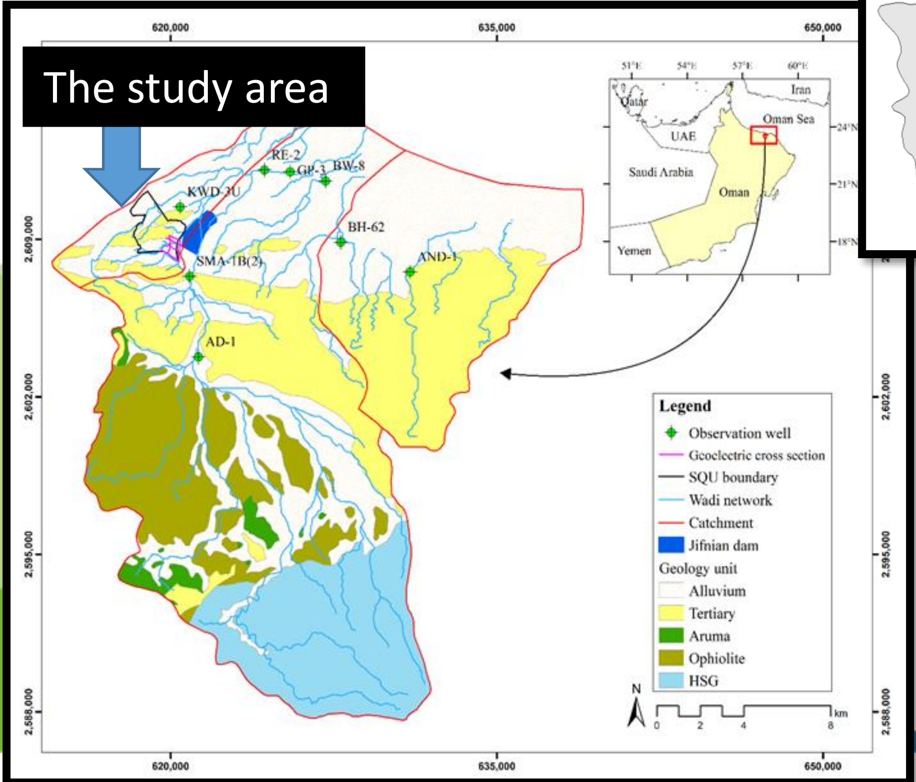
Resistivity sections inverted from the profile nb 12. A high resistivity rock residing beneath highly saturated rock. The model shows also that groundwater is very close to surface (5 meters and even less).

Impact of Al-Jifnain dam on SQU shallow water problem

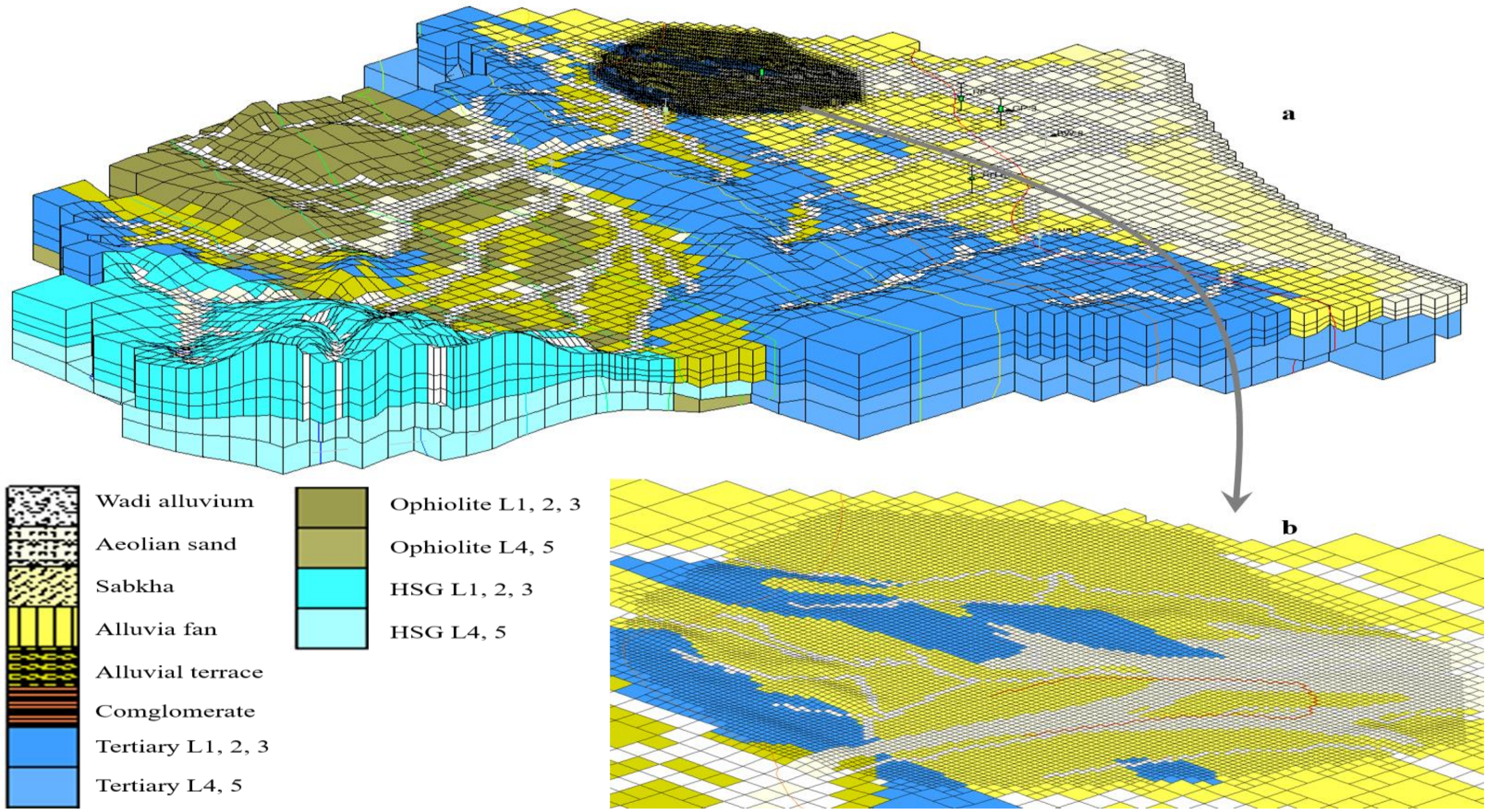
The catchment drains its water towards the study area. Given the subsurface geology of the study area, it is expected that the dam that is constructed in the vicinity of the SQU campus (just at its north border) will aggravate the issue of the shallow water table. We assessed the impact of the dam during the ponding of detained flashflood water numerically using Hydrus and MODFLOW-UnStructured Grid (MODFLOW-USG).







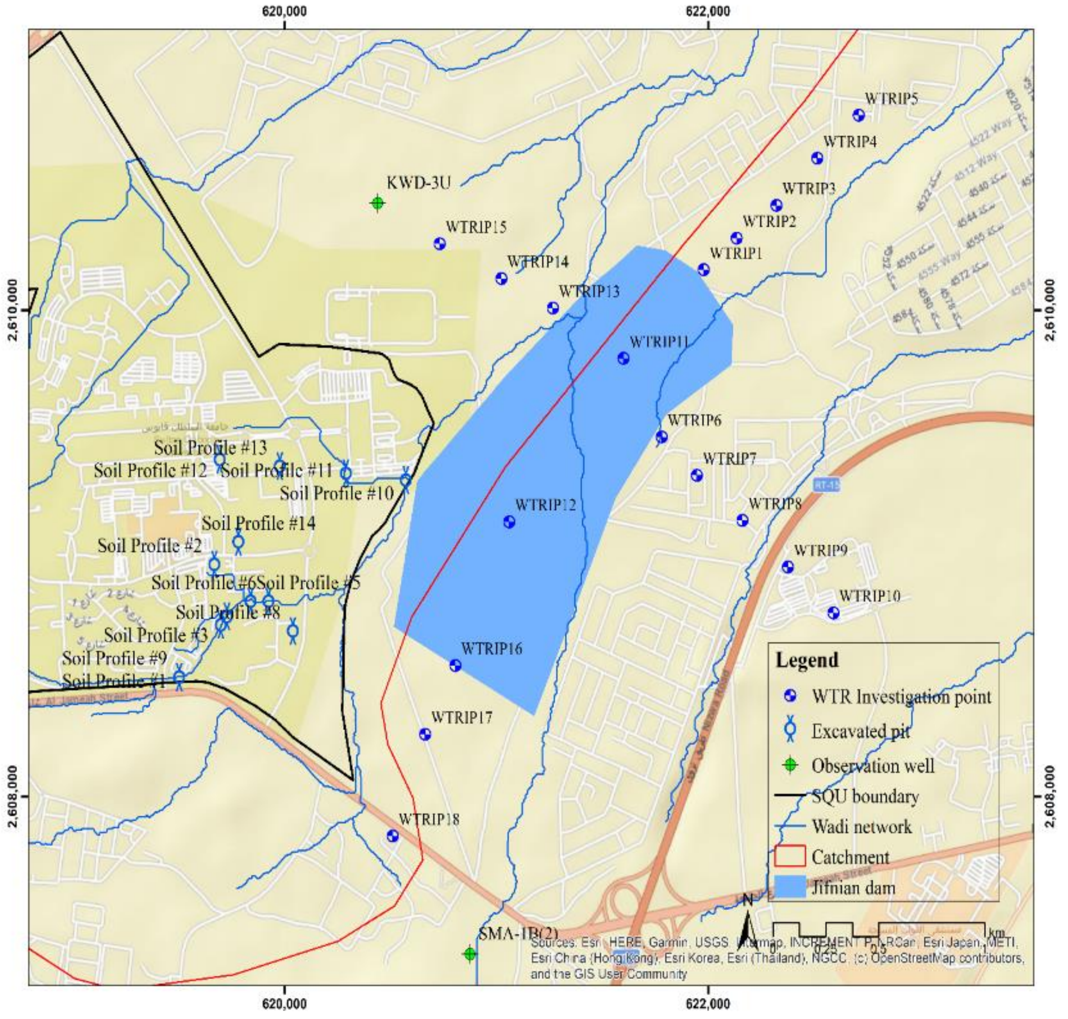
Groundwater numerical modeling – set up and structure



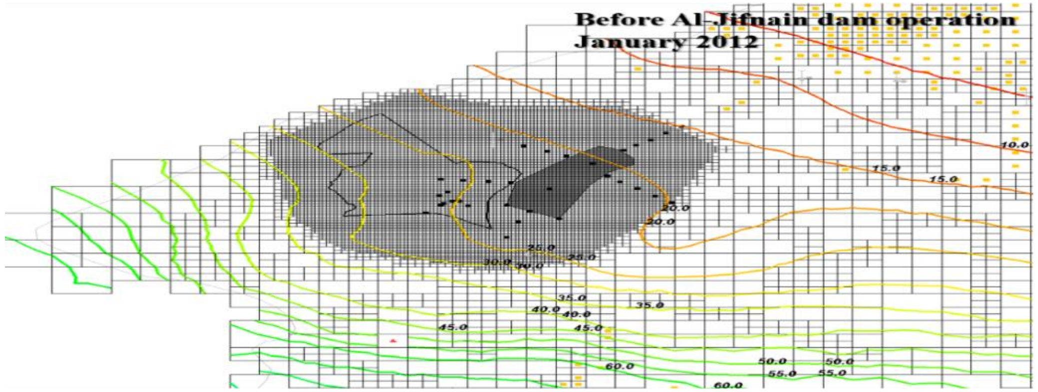
UnStructured Grid (USG) MODFLOW
Hardrock: 1500×1500 m
Alluvium: 500×500 m
Wadis: 250×250 m
Area of Interest: 50×50 m

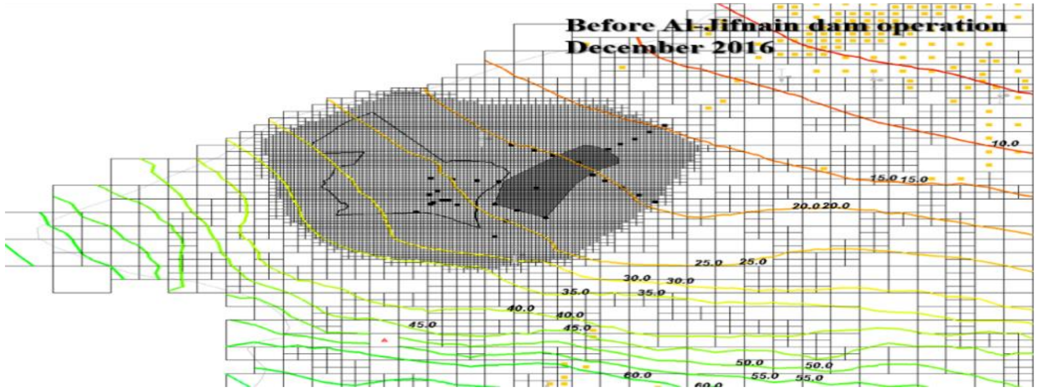
The effect of Al-Jifnain Dam on WTR

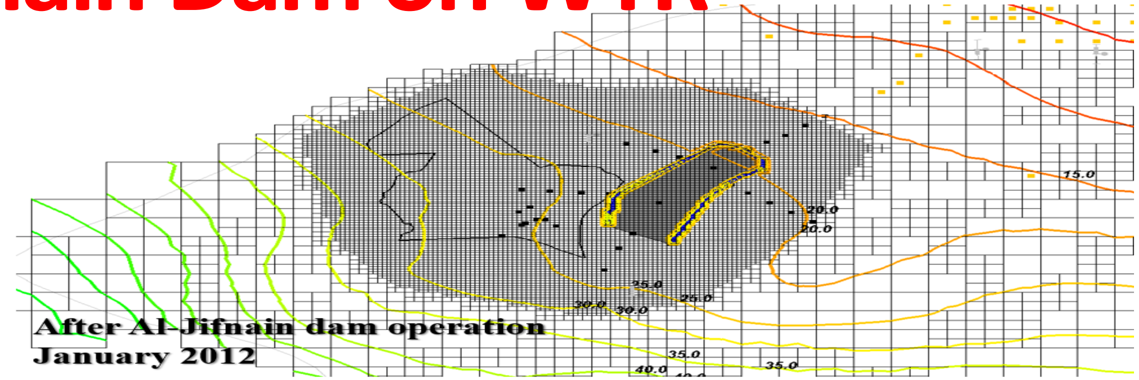
- The well-calibrated and validated groundwater model was employed to assess the effects of the Al-Jifnain dam on water table rise at its downstream and the Sultan Qaboos University campus.
- The right figure shows the selected points for investigating the changes in groundwater levels before and after the seepage events from the reservoir of the Al-Jifnain dam.
  - Two SMA-1B(2) and KWD-3U observation wells
  - 12 pits that drilled by the soil physics research team
  - 18 arbitrary points

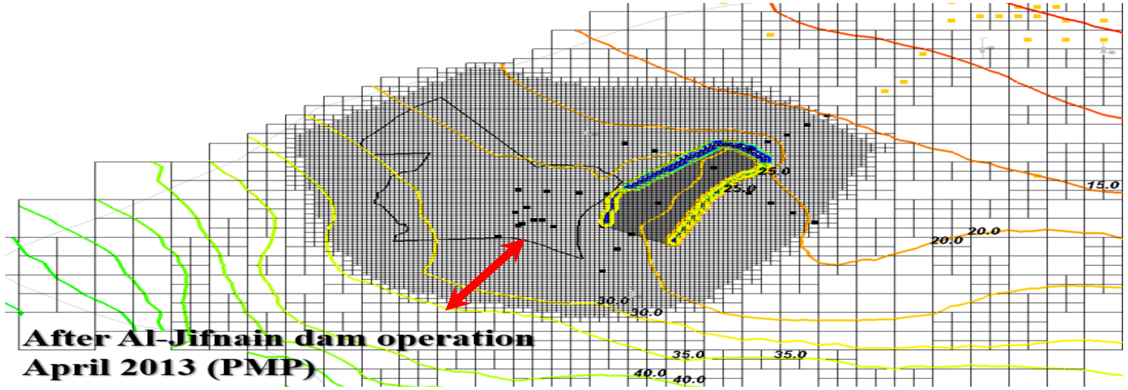


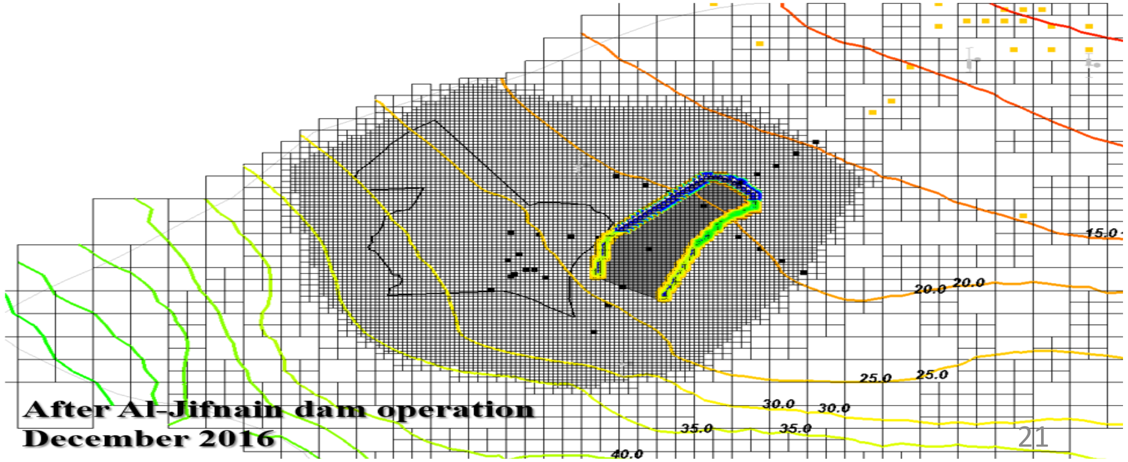
The effect of Al-Jifnain Dam on WTR





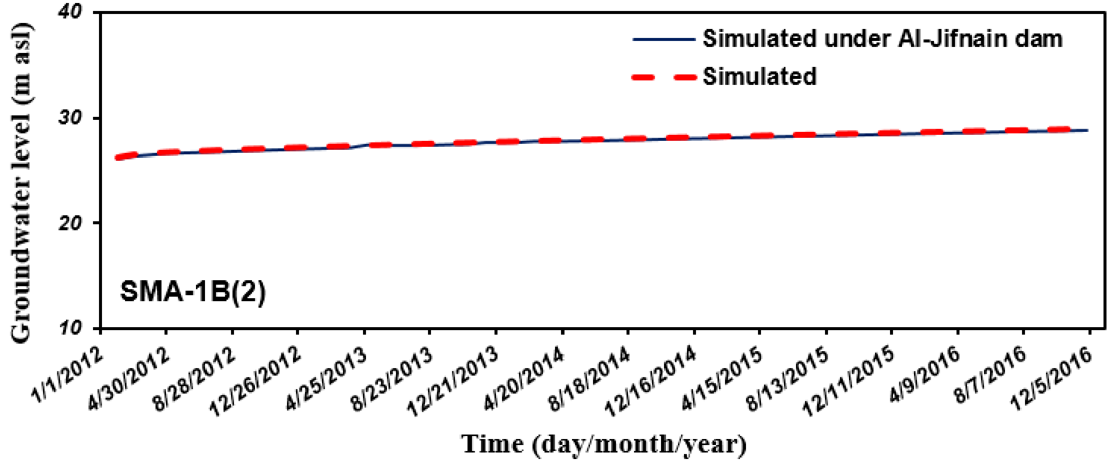


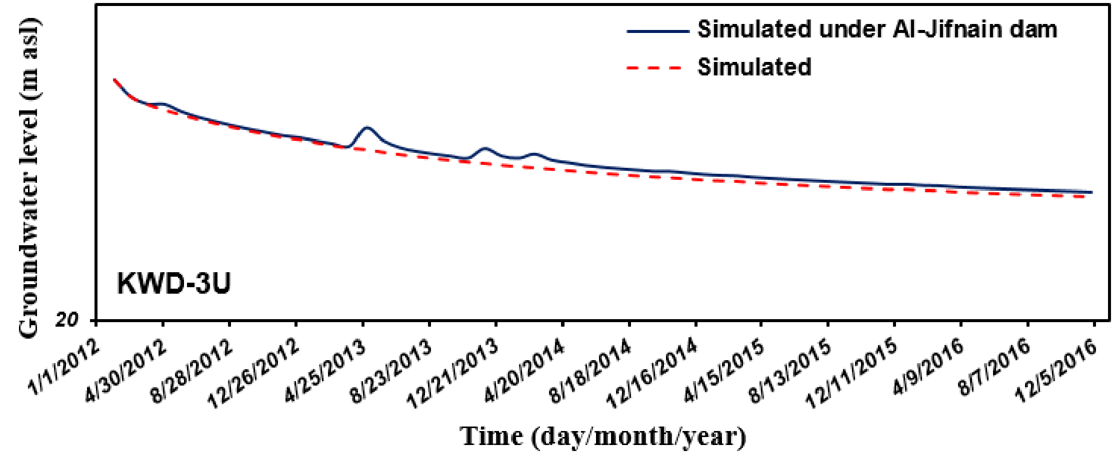


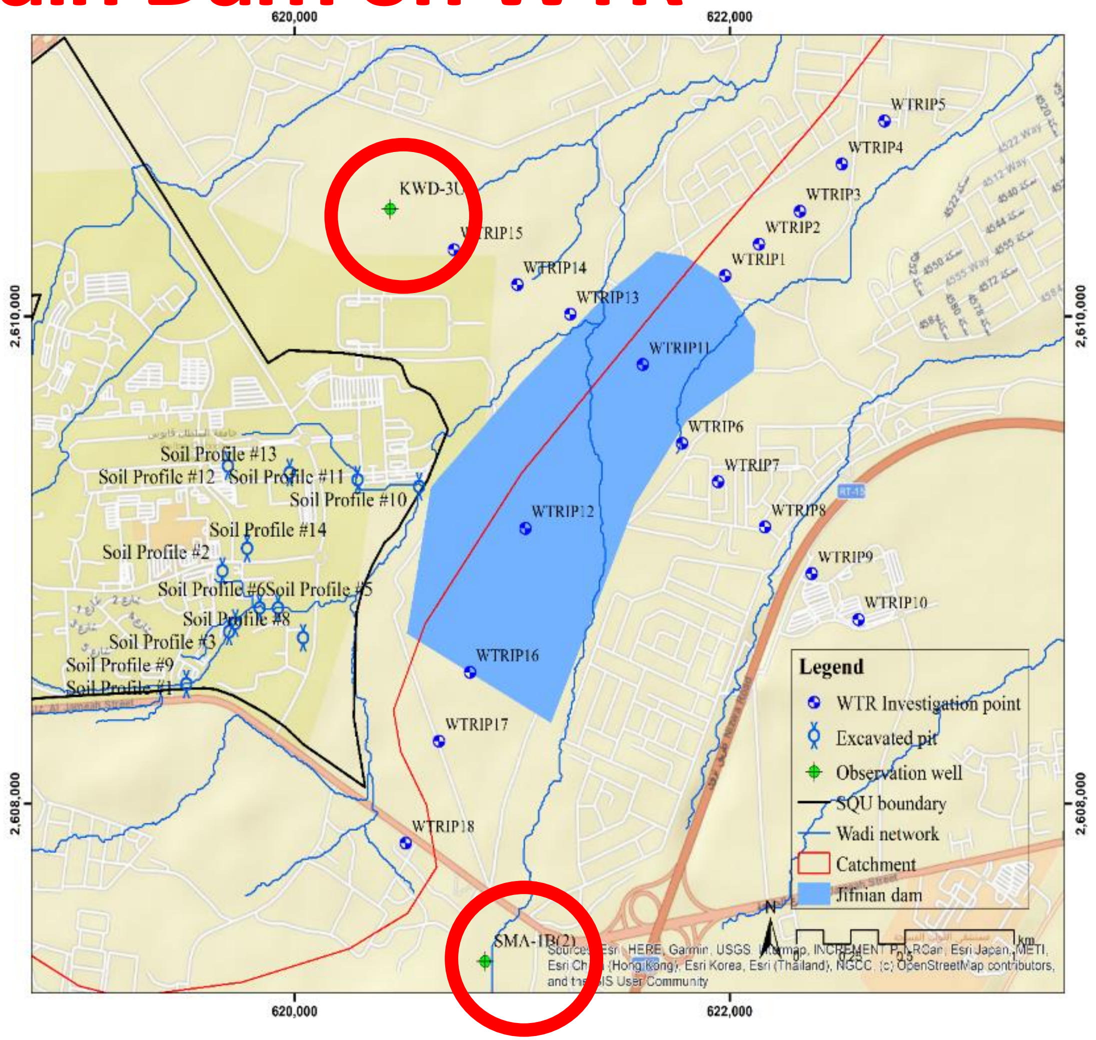


A significant groundwater level mounding with the length of more than 2000 m can be observed in April 2013.

The effect of Al-Jifnain Dam on WTR

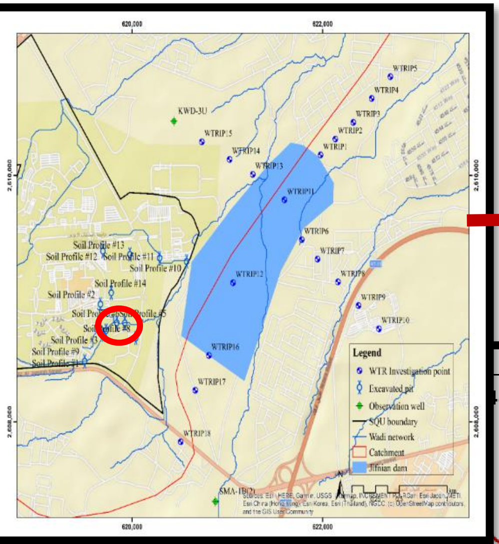


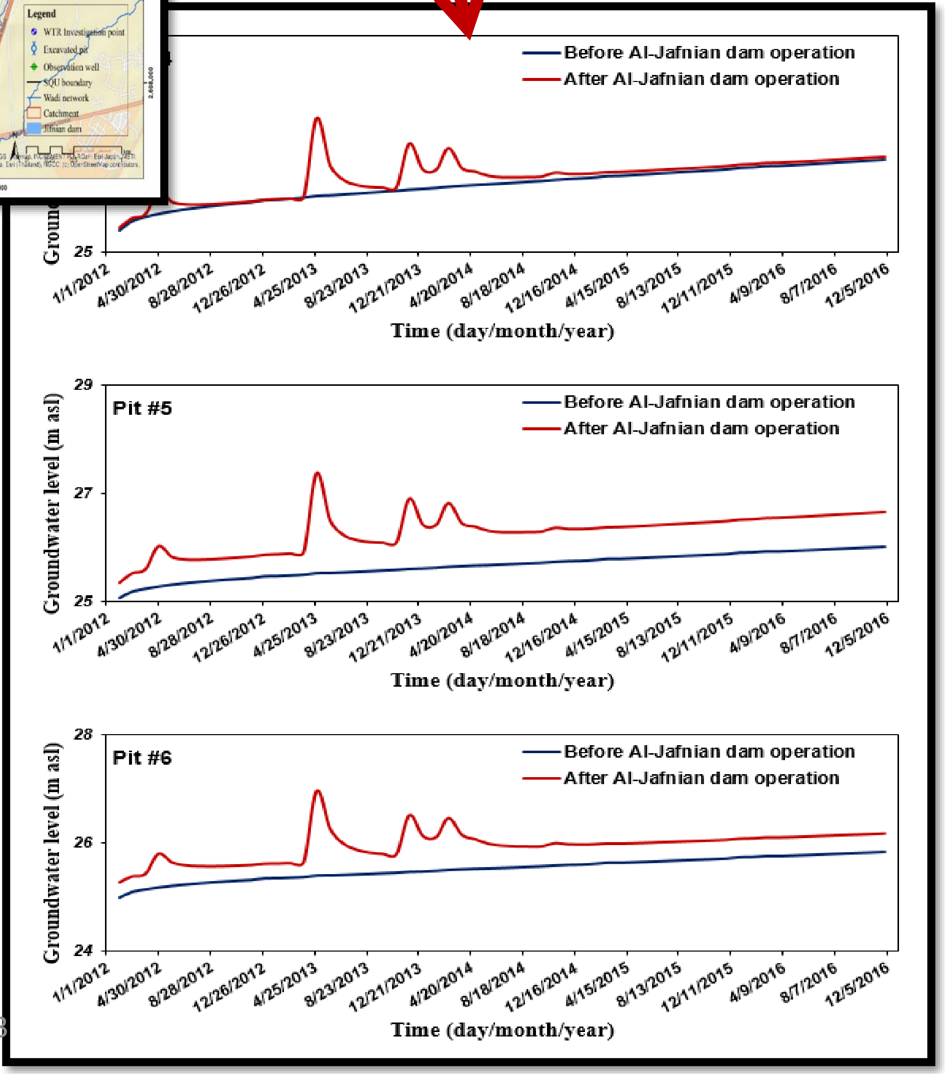


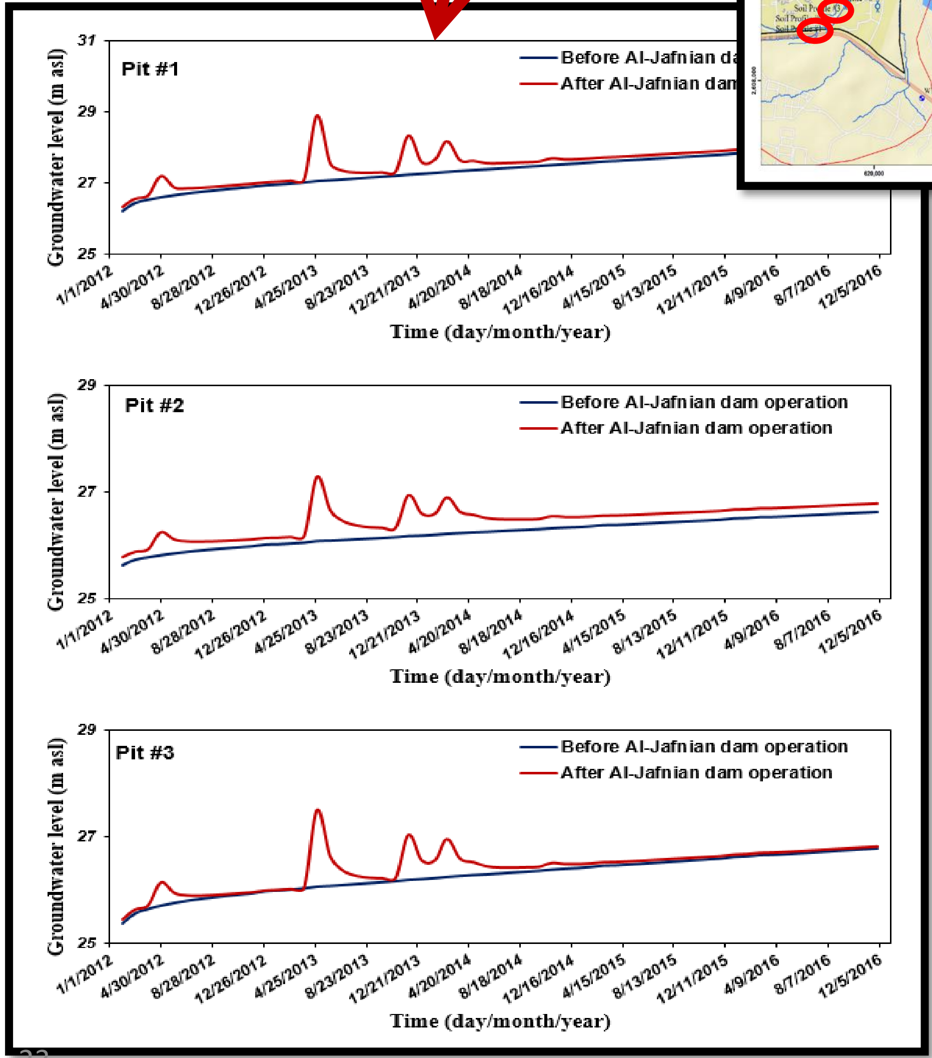


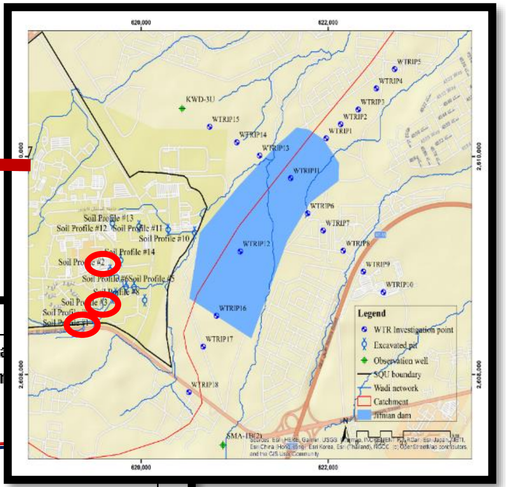
Al-Jifnain dam's effect is evident with almost half meter rise in groundwater level in the KWD-3U observation well, despite the fact that the well is located quite far from the dam's right side.

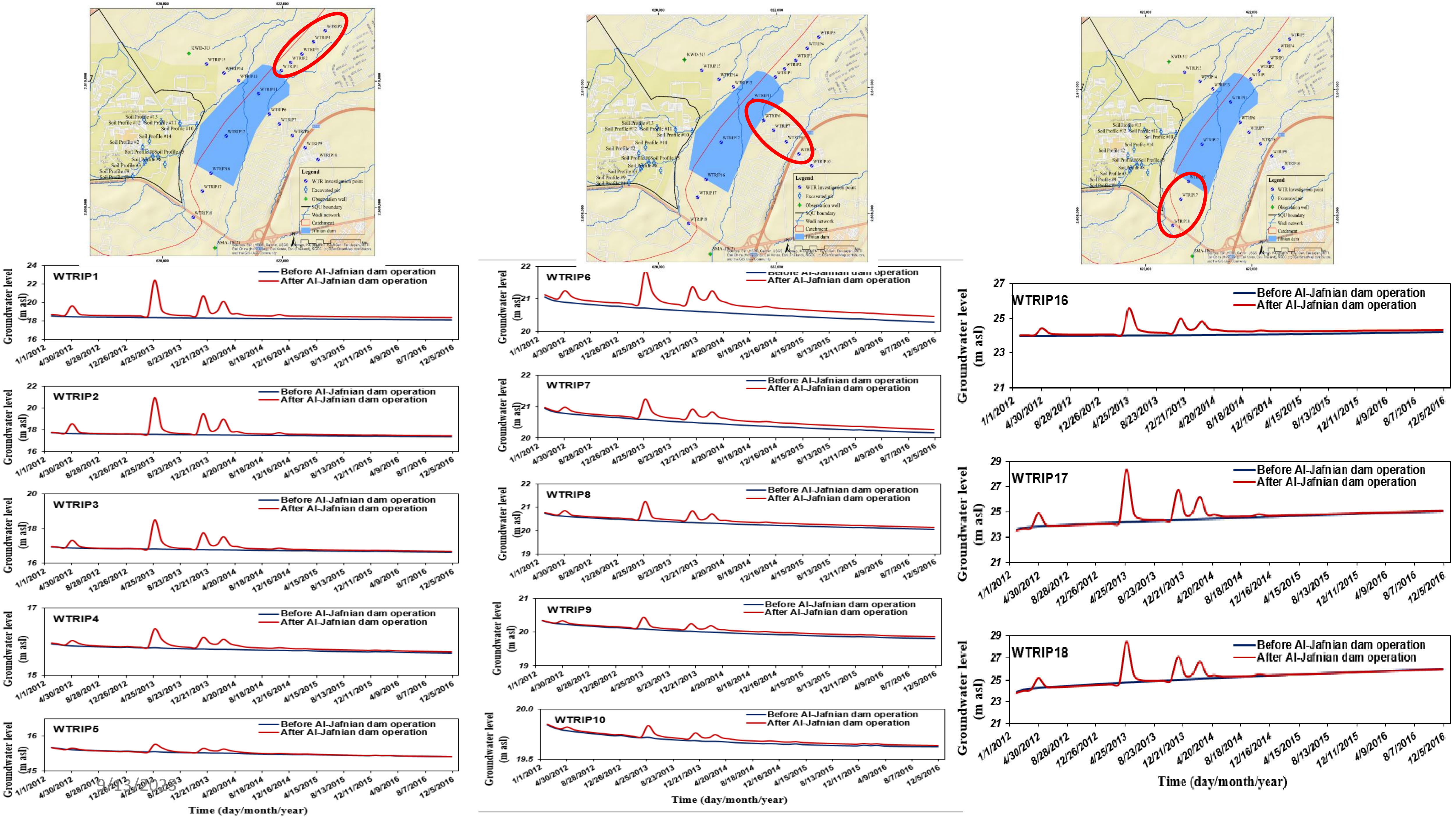
The effect of Al-Jifnain Dam on WTR











Legend
WTR Investigation point
Excavated pit
Observation well
SQU boundary
Wadi network
Catchment
Jafnian dam
KWD-3U
WTRIP1
WTRIP2
WTRIP3
WTRIP4
WTRIP5
WTRIP6
WTRIP7
WTRIP8
WTRIP9
WTRIP10
WTRIP11
WTRIP12
WTRIP13
WTRIP14
WTRIP15
WTRIP16
WTRIP17
WTRIP18
SMA-1B(2)
Before Al-Jafnian dam operation
After Al-Jafnian dam operation
Groundwater level (m asl)
1/1/2012
4/30/2012
8/28/2012
12/26/2012
4/25/2013
8/23/2013
12/21/2013
4/20/2014
8/18/2014
12/16/2014
4/15/2015
8/13/2015
12/11/2015
4/9/2016
8/7/2016
12/5/2016
Time (day/month/year)
9/13/2023

Conclusion and Remarks

- Mismanagement of water resources (irrigation practice, drainage of surface water, leakage from water networks), urbanization, and improper understating of subsurface geology may cause SWT problems.
- Water logging problems were found to cause the evolution of soil properties by lowering the permeability and developing Caliche layers that impede the percolation of infiltrating water.
- Modeling predicts that SQU campus will be significantly waterlogged by a shallow perched aquifer, which is fed by vertical seepage from dam's reservoir bed.
- The water chemistry suggests that the source of water is a mix of naturally infiltrating water, treated wastewater (irrigation water), and leakage from the potable water network (this necessitate management of those sources)
- Miscommunication (or even absence) between urban planners and hydrologists may create or exacerbate the SWT problem (the case of Al-Jifnain dam as an example).
- The shallow subsurface layer that hosts the water in SQU is of low permeability, hence water seeps out at a slow rate (around 6-10 cm/day rise in the trench). This limits the possibility of draining the water by vertical wells. Drain it naturally by engineered trenches (horizontal drains) and discharge the collected groundwater somewhere out of the campus could be the solution.
- It was evidenced that after reducing irrigation by 48% across the campus along with maintaining the network pipes, wet spots were reduced.
- There is ongoing experimental work to test the feasibility of using a Bio-engineering solution to lower the water table. Reeds were used in large field-scale experiments and were found to lower the water table by transpiration at a rate of 11 cm per day.

Recommendations and Possible Mitigation Measures

1. Urban development is inevitable and will continue, especially, under a continuing economic growth. Therefore, under the existing practices of water supply, control and irrigation of urban plants the WTR problem will likely to continue and appear in new areas in the future. Hence, prevention of WTR problem reoccurrence in the developed or the newly developed urban areas is of paramount importance. Drainage techniques suitable for urban settings should be prepared in advance.
2. Understanding the subsurface geology and its hydrological features is very important to assess the possibility of having SWT problems in the future whenever water leaks into the subsurface.
3. Consider the establishment of drainage system in the developed areas to drain the excess water. For instance, constructing trenches to convey the excess water to Wadi systems and/or detention ponds and lagoons with "green belts" on their banks of vegetation to collect and transpire-evaporate water.
4. Phreatophytic plants, tolerant to waterlogging and high groundwater salinity levels (xerophytes) should be propagated in megalopolises of GCC countries. Over irrigation practices of public gardens and parks should be stopped.
5. Municipalities of GCC countries - despite hyper arid and arid climatic conditions and originally deep regional aquifers underlying urban areas - MUST plan in advance the forthcoming rise of shallow water tables and emergence of perched aquifers. Otherwise, hydrologic retrofitting and adaptation to waterlogging disasters will be very expensive.
6. A permanent urban-scale groundwater monitoring system should be a MUST for any city development plan. *This systems should incorporate piezometers/monitoring wells tapping BOTH regional and perched (shallow) aquifers. Groundwater levels, salinities and temperatures in these monitoring wells must be regularly collected, stored (in the municipality groundwater database), processed and modeled.*

Acknowledgements

- Co-authors:
  - Anvar Kacimov, Hamed Al-Busaidi, Osman Abdalla, **Mohammed Farfour**, Said Al-Ismaily, **Talal Al-Hosni, Azizallah Izady**
- The authors acknowledge financial support from Sultan Qaboos University, Oman, through the grants IG/AGR/SWAE/10/02 and IG/AGR/SWAE/14/02 and the support of the Research Group DR\RG\17.
- Acknowledgment is also extended to the Ministry of Agricultural and Fisheries Wealth and Water Resources, Oman, for providing the data and logistical support.