GIS application in hydrogeological studies (Case Study: Dubai and Abu Dhabi Emirates)

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ABSTRACT

For the past two decades, The United Arab Emirates' groundwater and soil have become at risk of contamination, over-extraction and over-irrigation. However, the declining water quality and modest irrigation practices in many areas pressured farmers to install packaged desalination equipment that caused significant increase in the salinity levels in the soil as well as in the surface levels, leading to contaminants percolation to the groundwater aquifers.

This paper introduces ModeflowMap,an innovative GIS Solution developed for capturing groundwater parameters for thousands of wells and boreholes in Abu Dhabi and Dubai. This solution is designed as a primary effort to summarize the data relevant to the quantity, quality, chemical and biological properties, as well as the locationand type of groundwater resources. Such data helped track and analyse the status and uses of groundwater reserves. The findings assisted also in improving and promoting efficient use of water resources in both Emirates.

Such comprehensive effort is necessary to fully understand the state of UAE's groundwater and soil resources in order to support the development of effective policies and efficiently manage these resources.

Among the key findings of this project is the strong link of differences in groundwater levels to areas of irrigation and agricultural activity. The analysis shows that areas with fast declining groundwater reserves coincide with the areas of highest groundwater abstraction for agricultural irrigation. In fact, the water level in groundwater monitoring wells has dropped by more than 20 meters in Remah, and by over 14 meters in the Liwa Crescent over the course of only 12 years.However, in some areas, this trend has reversed over the past few years – in Madinat Zayed for example, groundwater levels have risen since 2010 following a decline for many years, which can be mainly attributed to a reduction in agricultural activity.

Keywords*:*groundwater monitoring, GIS solutions, Groundwater modelling, soil salinity mapping, groundwater well inventory, ModeflowMap, software development, thematic maps, GeoDashboards.

INTRODUCTION

No doubt, water is one of the prime elements responsible for life on earth. It circulates through the soil just as it does through the human body, carrying, dissolving, and renewing nutrients and organic components.

Since, water in the UAE is in very short supply, the required measures for protecting water are necessary to maintain an efficient irrigation system, which impacts the vegetation cover's health. In fact, groundwater accounts for 94 % water consumption in the agriculture sector in some emirates like Abu Dhabi and Dubai. But the current usage of groundwater reservoirs is about 15 times more than the natural recharge rates. Moreover, the 2017 Food Sustainability Index (FSI) ranked the Emirates at the bottom of 34 countries for sustainable agriculture, with the high use of dwindling resources in aquifers a key factor.

This contributes definitely to increasing agricultural productivity within such unproductive arid environment; however, it leads also to overexploitation of UAE's aquifers and degradation of the water quality resources. This unsustainable water balance and the variability of water quality turn the UAE groundwater to an increasingly scarce and limited resource. Therefore, to reverse this situation, it is essential to be proactive and adopt multiple measures focused on controlling runoff water and groundwater uses for different purposes especially farming. Many studies and projects were conducted to assess and control agricultural irrigation activity. For example, Law No. (15) of 2008 Concerning Protection of Groundwater in the Emirate of Dubai had been implemented by H.H. Sheikh Moahmmed Bin Rashid Al Maktoum, Ruler of Dubai to strengthen the rules around illegal groundwater use and requires farms to have meters. The implementation of this law helped reduce groundwater use and slow down the depletion of UAE aquifers, helping to support the longer-term future of the agricultural sector, forests that provide benefits and natural ecosystems.

Such efforts definitely lead to maintenance of better-quality water, and restoration of deteriorating aquifer systems in many areas. The use of advanced irrigation technologies, construction of groundwater-recharge dams, and growing salt-tolerant crops are suitable agricultural approaches. Establishment of data banks and the application of advanced groundwater modelling and isotope hydrology techniques are powerful water-resources management tools.

This research work presents ModeflowMap, an innovative enterprise GIS Solution comprising of multiple modules that cover critical requirements for better simulation and prediction of groundwater conditions. This enterprise solution monitors the field data collection, the image processing and vector layers extraction, the data processing and quality control, the geospatial analytics and the dissemination of the results in order to predict the groundwater conditions for future years and monitor water uses in agriculture real-time. This solution supports government entities as a decision support tool including all actors involved in water management and water policy-makers at field level.

Materials and methods

The project, which lasted for 72 months and that was carried out in three main phases, included the inventory of both groundwater wells and soil salinity in Dubai and Abu Dhabi.

In the first phase, all the wells were assigned a unified number during field visits that recorded pumping rates, groundwater levels, salinity, condition and the purpose for which each well is being used for. The second phase included updates to available soil salinity and fertility measurement data. The soil samples were taken from a selected few of the 25,000 farms in both Emirates, and then analysed to identify the soil type, salinity and quality. This will help develop plans to determine the sustainability of these farms and classify them in terms of soil quality. This aims to drive investment to the agricultural sector, establish the best ways to manage these farms and discover the most suitable crops to maintain soil and water quality.

In its last phase, the ModeflowMap solution analyzed all the water and soil data to produce an atlas of aquifers in both Emirates - the very first of its kind in the UAE. The analysis provides a summary of groundwater sources in terms of their quantity, quality, natural, chemical and biological property, location, depth and type. This information is displayed in the form of annotated maps, graphs, sections and infographics. The atlas includes also the results of the Well Inventory initiative which was conducted using ModeflowMap Mobile module, detailing the location, type, depth and use of wells.

ModeflowMap web module disseminates all results as interactive maps and GeoDashboards providing decisionmakers with up-to-date, accurate data on groundwater and soil quality.

This conducted effort helps establish a baseline for soil behaviour throughout the seasons in order to identify key performance indicators for the implementation of a future management plan for agricultural soil. Also, the development of a local comprehensive agricultural soil management plan in collaboration with concerned government entities should consider other aspects other than soil such as good agricultural and irrigation practices, pressure-optimized irrigation systems, optimal timing and irrigation quantities, appropriate leaching fractions, and the introduction and testing of salinity adapted crops.

The Groundwater Well Inventory Throughout the duration of this project, 117,859 wells were surveyed in Abu Dhabi while 47,433 wells were visited in Dubai. It took sixteen field teams in Abu Dhabi and 8 more teams in Dubai all working for two years to complete the job. The majority of wells are located on farms and in forests with the exception of some remote desert locations. Special teams with experienced staff and special equipment were assigned to these remote desert locations, where off-road driving capabilities and extensive safety measures were essential to the survey's success. For each surveyed well, more than 100 parameters were recorded. These parameters included coordinates, depth, diameter, and casing material of the well. Additionally, the use and operational status of the wells were assessed. Where possible, groundwater level, salinity, temperature, and pH were also measured. The teams recorded pump operation time, well discharge, and selected farm data at each of the wells.

One of the most important aspects of this project is the modelling of the soil erosion, therefore, The MODFLOW and RUSLE erosion method were chosen to simulate and predict groundwater models along with generation of soil loss for sheet and rill erosion. The cartographic representation of the different factors and parameters of results along with the water quality are equally important and covered in this project. Finally, further analysis was carried out to examine the link between the soil erosion and water quality by identifying the relevant dominant factors.

The following provides information of the methodology adopted to meet the requirements and a brief description of the context of the activities undertaken for the well soil salinity surveys:

- Phase 1- comprises mobilization of survey teams, design of the GIS solution for field data collection, analysis and prediction, purchase of equipment, and the development of work procedures (data dictionaries, SOP's, EHS, and QA & QC).
- Phase 2 comprises the actual well & farm surveys, including groundwater and soil sampling and analysis.
- Phase 3 comprises the interpretation of survey results, the preparation of databases, maps, and the groundwater atlas.

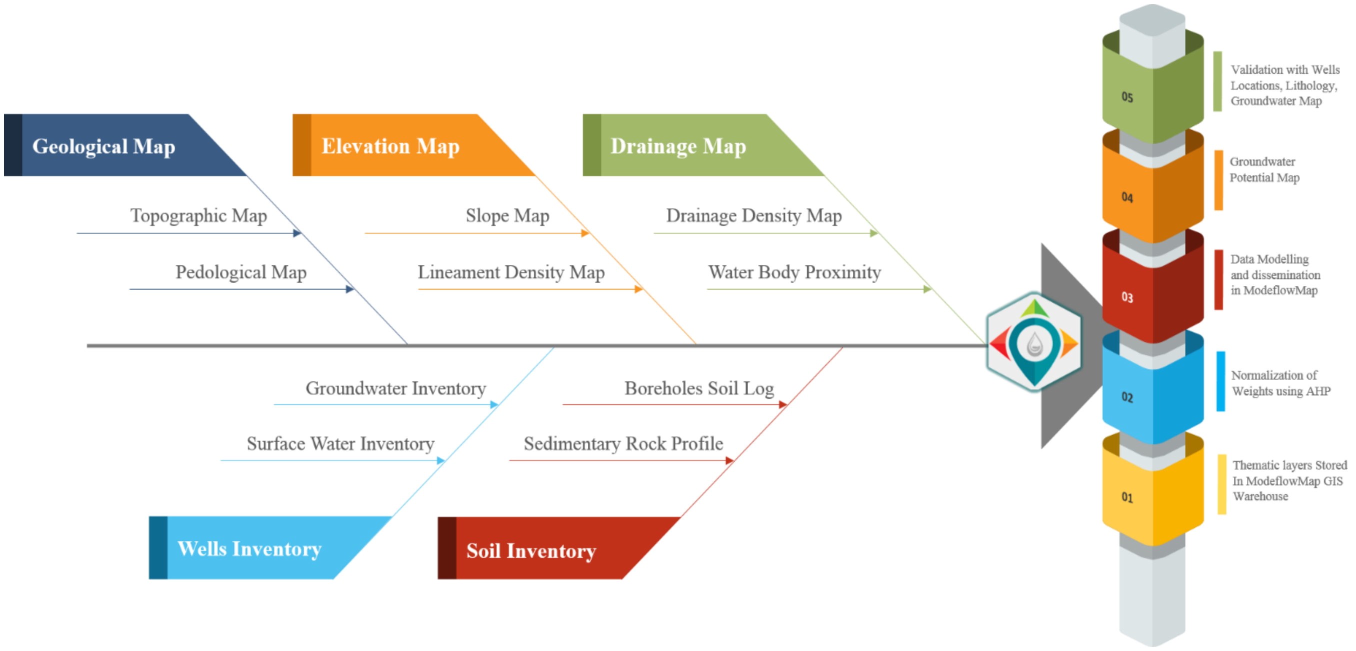


Fig.1- Flowchart Showing Summary of input and output of ModeflowMap

A proper methodology is critical to process all the different data inputs in an efficient and accurate manner, especially the high-resolution imagery acquired for automatic generation of vegetation cover in the country.
ModeflowMap as an enterprise GIS Solution is not beneficial only for the planning phase of groundwater resources management; but it also introduces tools to automate processes such as the design, the collection, the analysis and the dissemination of thematic maps through use of advanced geoprocessing scripts. Accordingly, the ModeflowMap has several components to cover these requirements (Figure 2) where users have access to different interfaces ranging from field inspection, to mapping results, calibrating groundwater models and dashboard visualization.

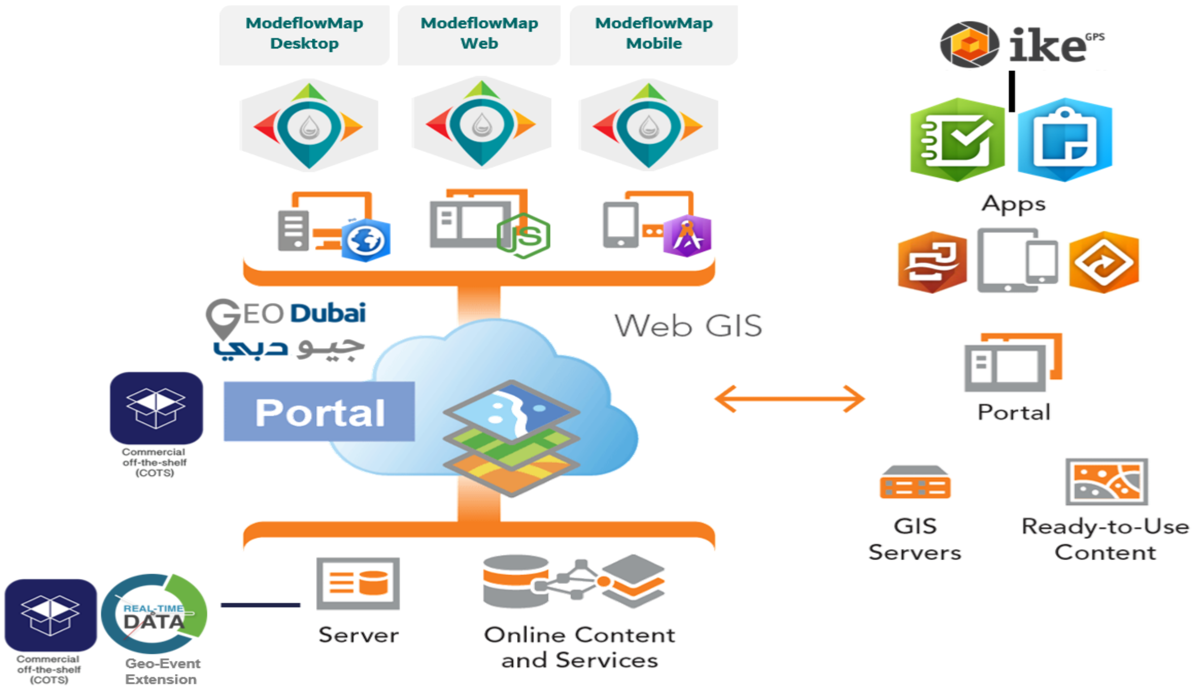


Fig. 2- ModeflowMap Main Components (Desktop, Mobile and Web, Databases, Servers, …etc.)

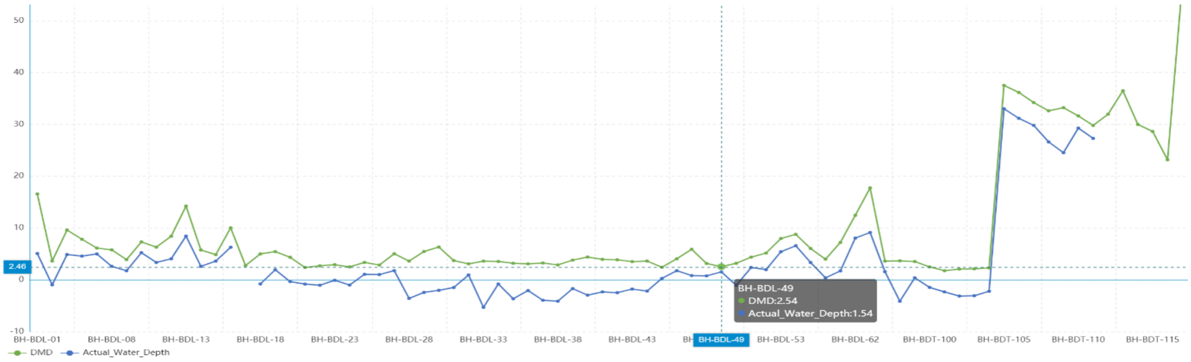
Results and discussion

This project is a six- year effort to register, collect and analyze data for over 118,000 wells in Abu Dhabi and 47,433 in Dubai. This project builds a strong foundation from which we can better manage UAE's groundwater and agriculture resources into the long-term future. Experienced technical teams from Environment Agency of Abu Dhabi and Dubai Municipality had been canvassing both Emirates to collect this data since January 2016 -

resulting in more than 36 months of technical fieldwork. With durable hand-held GPS-equipped devices where ModeflowMap Mobile solution was installed and configured, the field teams recorded the location, type and depth of each well, and measured the flow rate, depth, salinity and hydro-chemical profile of groundwater at each well head. A registration plate was fixed to each well and the data is uploaded into ModeflowMap GIS database. Soil samples were collected from four different depths on selected farms and each was analyzed for soil type and salinity. A portion of these soil samples were also sent to a specialized laboratory for further and more detailed analysis. In 2017 the teams have continued field surveys and have completed recording data from an additional 34,200 wells and collected 400 additional soil samples for laboratory analysis.

Given, the significance of the coordinated effort between Government departments to collect and share data related to groundwater resources, the task of implementing ModeflowMap as an integrated solution for collecting critical groundwater wells information in order to enhance the simulation and the prediction of groundwater conditions and groundwater/surface-water interactions is of great value for different departments. In fact, the results of this project support groundwater scientists in establishing a clear agenda for the implementation of necessary framework of policies, partnerships, standards, data, procedures, technology and institutional capabilities that collectively will comprise the UAE Groundwater Resources Hub.

As a result, the processing of this historical wells data combined with inspection results is key to predict and simulate pressures, temperatures, sodium and other water related conditions in order to prevent non-controlled



and harmful drilling procedures. The mobile module of ModeflowMap can be also customized further to create a public version to share with farmers as a self-inspection tool of farm owned groundwater wells. Such approach will engage the public more within the governmental agendas and ease the overload on groundwater control departments.

Fig.3- Predicted Water Level vs GWL of Sewer Boreholes 2020- ModeflowMap Web Module

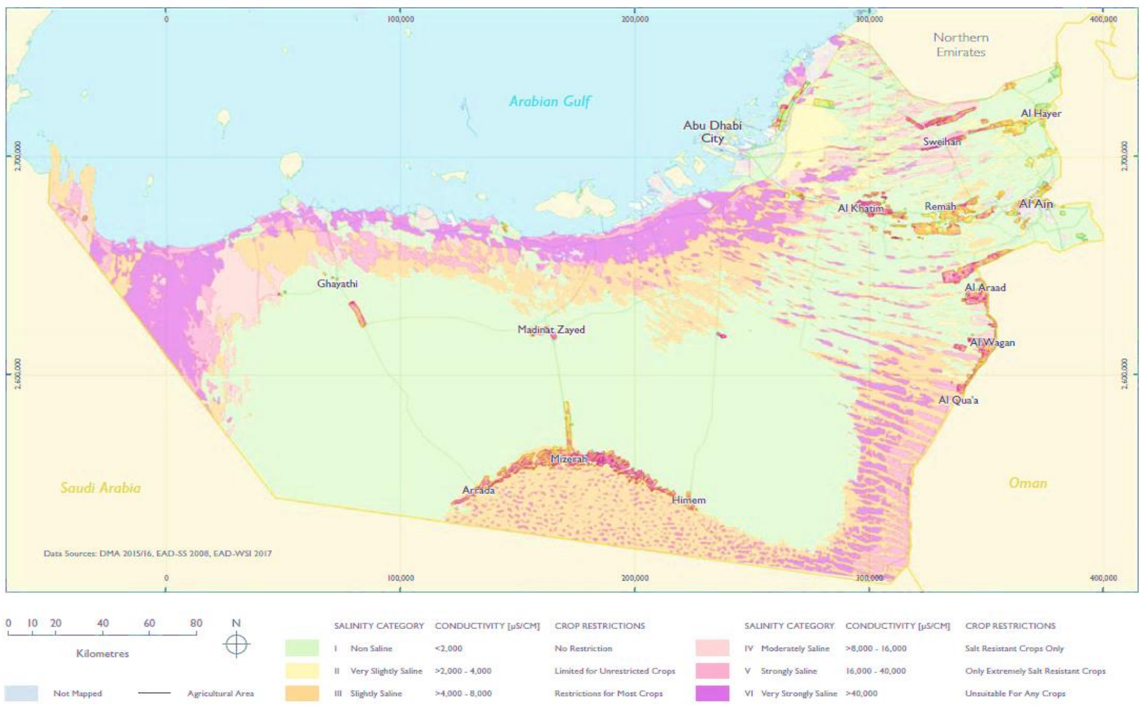


Fig. 4- Soil Salinity Map by Layers

The classification of groundwater quality is often related to overall mineralization, which can be expressed as the concentration of total dissolved solids (TDS). The seven most common ions (major ions) largely determine the TDS value. However, minor constituents such as phosphate, boron, fluoride, and metals like iron, manganese, zinc and others, also have an effect on groundwater quality.

Even in small concentrations, they restrict groundwater use and affect human health. They appear in quantities of nanograms, and up to a few milligrams per litre. To ensure groundwater quality, Environmental Agency - Abu Dhabi (EAD) in Abu Dhabi and Dubai Municipality respectively set thresholds for the maximum concentration for each constituent. These thresholds are among the strictest worldwide. The acceptable value differs between groundwater intended for domestic use, irrigation, or livestock supply. The government regularly samples wells across the country to monitor the groundwater quality.

Both natural processes and human activities affect the groundwater quality. The minor constituents are helpful for tracing the natural groundwater evolution and determining the causes of groundwater pollution. For instance, elevated boron and phosphate concentrations are related to the inflow of fertilizers from irrigation water or detergents from wastewater into the aquifer.

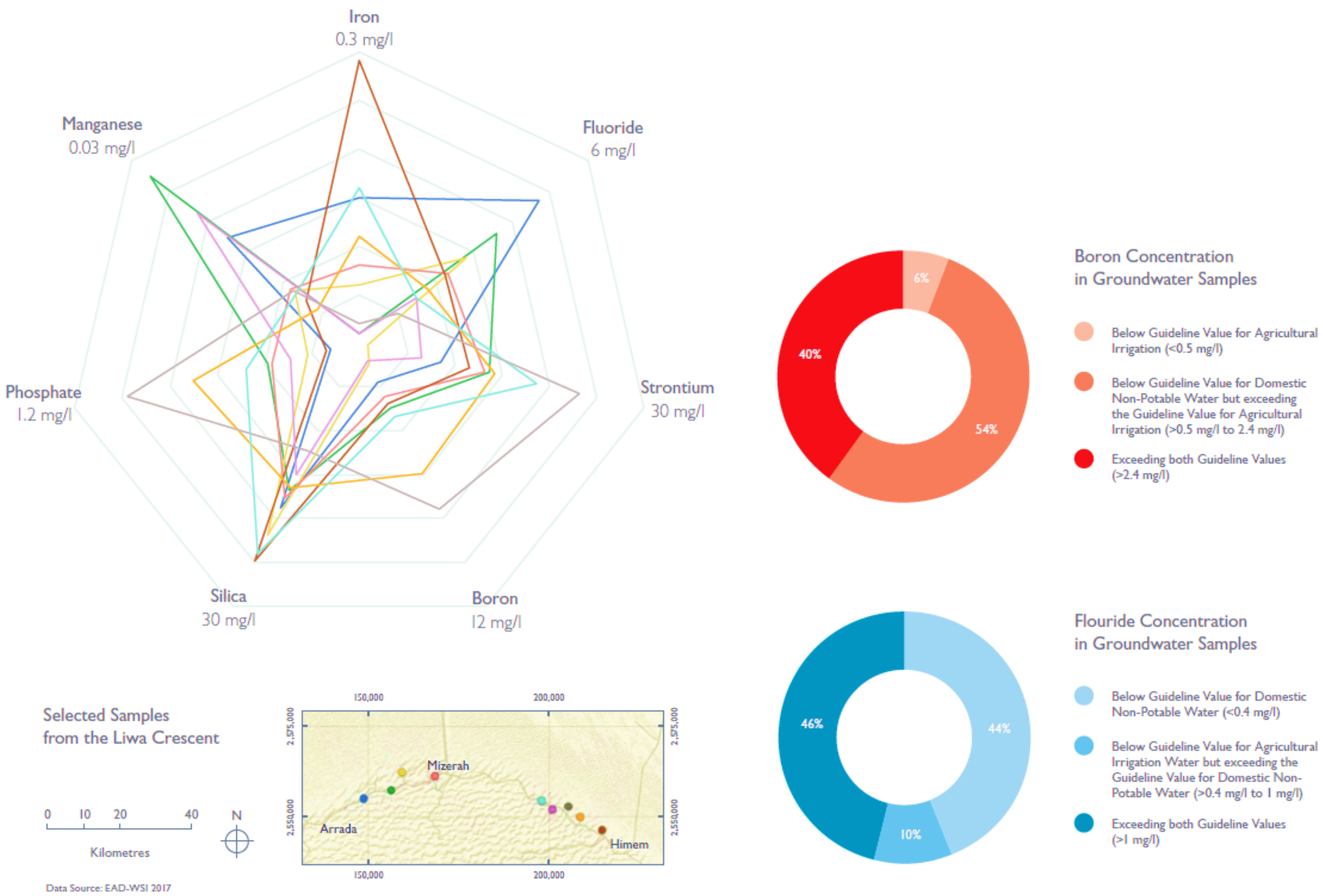


Fig. 5- Groundwater Quality (Iron, Fluoride, Strontium, Boron, Silica, Phosphate, Manganese)

Conclusions

Among the great number of abiotic stress affecting plants, drought and salinity are the most severe and stronger ones that limit plant growth and crop productivity in agriculture worldwide. This stress could have damages exceeding the sum of that attributed to all other natural disasters, and when they happen together promoted devastating changes in plants subjected to them.

This project presents the results of groundwater wells inventory and soil salinity mapping in Dubai and Abu Dhabi Emirates using ModeflowMap, a powerful and an enterprise GIS solution with great interest and utility for decision makers, groundwater researchers, and operations crew for water resources planning, survey and control. The use of ModeflowMap enabled full and streamlined integration between groundwater departments in Dubai Municipality and Environment Agency of Abu Dhabi; it allowed the optimization of scheduling and work assignment and helped gain real-time insight for operational improvements.

In total, 117,859 groundwater wells were registered, out of these 47,433 wells were identified in Dubai while 70,426 were recorded in Abu Dhabi. Of the wells surveyed 43.9 percent were found operational. Most the wells belonged to agricultural areas, followed by forests and remote well fields. 141 wells were found in areas outside redefined municipal boundaries. Depth to groundwater were measurements recorded for 24,312 wells showing that approximately a third of the wells were dried-out. With an average depth of 102 meters (m) below surface, and large regional variations according to abstraction and apparent differences in hydrogeological setting.
The groundwater salinity was measured in 15,286 operating wells including some bailer samples. Both in the Al Khazna / Sweihan as well in the Al Hayer - Al Ain - Al Wagan areas slight to medium brackish groundwater is prevailing with better quality of water near the UAE - Oman border. Discharge measurements, carried out for 8,832 wells, showed an average discharge rate of approximately 16.15 m3 /h, ranging from a minimum of 0.13 m3 /h to a maximum of more than 180 m3/h.
The results of the soil salinity analysis show a marked fluctuation of salinity values with the seasons. The highest variations are recorded in the top horizons, while the lower horizons also react but in a much-reduced manner. Knowing that on average every mm of irrigation water (1l/m2) at an EC of e.g. 16,000 MicroS/cm tends to add about 10 g of salt per m2 of the soil. Further assuming a yearly value of 3500 mm for palm tree irrigation, about 35 kg of salt is applied per m2. This amount of salt needs to be leached out by proper irrigation management. The winter season shows the lowest value in salinity due to lower evapotranspiration and a higher proportion of the irrigation water contributing to the leaching of salt. Rainfall is not a key factor. During the summer season, due to higher evapotranspiration and less water infiltrating into the soil, salt tends to accumulate at the surface.
In order to enable the drawing of location maps showing name and extent of land use features supplied by a well, the data integration comprised the use of farm boundary data as supplied by stakeholder organizations then ModeflowMap desktop module was used to correct the positional accuracy of some wells close to plot limits and assign these automatically to the correct farm parcels. In addition, satellite images were used to identify targets in uncertain areas with on-screen digitizing in Geodubai supplied data of 60 cm resolution.
To match DM and EAD's well data recorded in the past with wells recorded by the well inventory team, FME Workbench was created to link between the new and the previous well names by applying GIS analysis incorporating previously permitted and recorded wells and reporting the survey data in three-month batches.

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