Dubai Groundwater well survey and soil salinity field data collection using ModeflowMap

Lala El Hoummaidi1, Dr. Abdelkader Larabi2
1. Laboratory Analysis and Modeling of Water and Natural Resources (LAMERN) Mohamed V University, Mohammadia School of Engineers, Rabat, Morocco
2. Laboratory Analysis and Modeling of Water and Natural Resources (LAMERN) Mohamed V University, Mohammadia School of Engineers, Rabat, Morocco

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ABSTRACT
In Dubai, groundwater and soil are threatened by over-irrigation, over-extraction, and contamination. Furthermore, the installation of packaged desalination equipment by many farm owners to overcome the challenges of deteriorating water quality caused a significant increase in salinity levels in the soil and surface level contaminants percolating to the groundwater aquifers. Thus, well-planned and executed programs should be considered to save Dubai's aquifers. As we learn more about groundwater issues in Dubai Emirate, it becomes very clear that these issues require collective and integrated responses in order to better manage the groundwater resources in the long-term future.
Therefore, surveys capturing the groundwater parameters for 47,000 groundwater wells in Dubai were successfully conducted using durable smartphones where Dubai municipality teams recorded the location, type and depth of each well, and measured the flow rate, salinity and hydro-chemical profile of groundwater at each well head. This comprehensive effort is necessary to fully understand the state of Dubai's groundwater and soil resources and support the development of effective policies to efficiently manage these resources.

This article describes the methods and the results of the field survey conducted using ModeflowMap Mobile application, an innovative field inspection solution developed to monitor and conduct different types of inspections of groundwater wells. In conclusion, ModeflowMap comprised an important support tool for decision makers to ensure that wells are not being over-pumped, the groundwater in the wells is of optimum quality and there’s no long-term risk to the groundwater wells through automation of work assignments, agronomic data capturing and groundwater samples collection from each well, it also integrates with other enterprise GIS systems, and generates reports and maps for monitoring inspections real-time.

Keywords: Groundwater; GIS; field data collection; ModeflowMap; software development; Modflow; soil salinity, thematic maps, GeoDashboards.

INTRODUCTION

Arid and semi-arid landscapes such as those found in most parts of Dubai exist within an extremely sensitive ecological balance. Men and indigenous plants historically managed to adapt to this water-scarce environment without disrupting the pre-existing equilibrium in this delicate ecosystem.
Dubai has one of the world's highest levels of domestic waste and water consumption per capita. Ambitious programs for afforestation, landscaping within urban and rural regions, as well as intensive food production are transforming the arid lands of Dubai in a way that is totally alien to its older inhabitants. This situation offers a unique chance in devising a rural development scheme with a string of self-sufficient villages.

At present, fossil, non-renewable groundwater resources are being depleted to an alarming extent. Renewable groundwater tables of inland aquifers that depend on rainfall are drastically falling in level and increasing in salinity due to non-sustainable irrigation methods and the infiltration of seawater. Municipal waste traditionally has been dumped in landfill sites, and at best subjected to only little treatment. These sites are endangering the groundwater as a result of the various pollutants they contain that are seeping into the groundwater. Areas used for farming, landscaping, or afforestation are showing alarming levels of soil salinity. A good number of the millions of trees planted during the last decade are dying off or being damaged as a result of drought or salinity stress. Dust storms and land erosion are becoming increasingly numerous where there is increase in soil salinity.

This research presents theenrichment of groundwater models through well data survey conducted by Dubai Municipality using 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.

Study Area: Dubai Emirate

The aim of this paper is to perform study analysis of soil salinity and related groundwater conditions in Dubai where cultivated area covers up to 254,918 ha (arable land and area under permanent crops) and 190,388 ha of permanent crops.

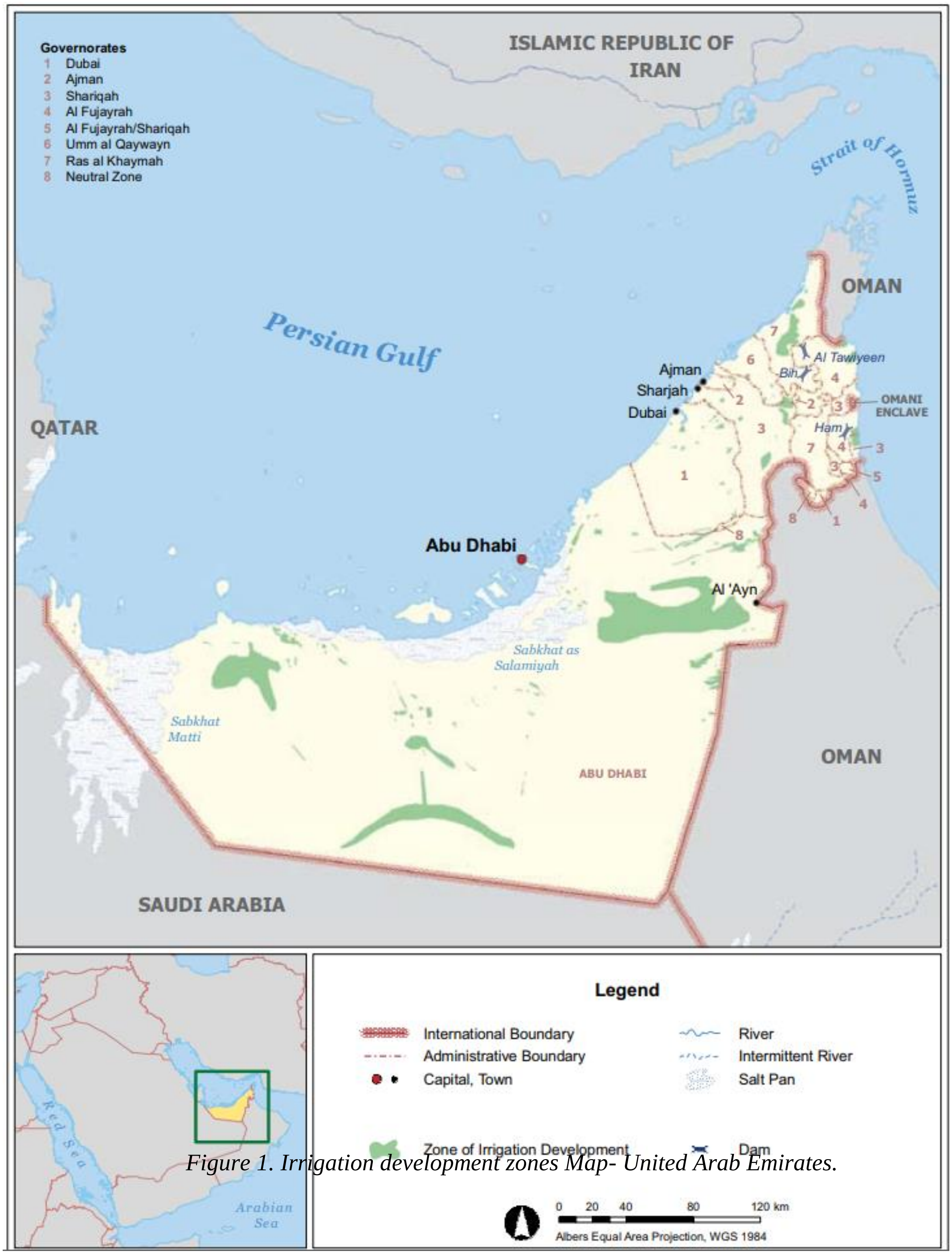


Figure 1. Irrigation development zones Map- United Arab Emirates.

Groundwater
The first settlements in the UAE trace back to the Late Stone Age between 6,000 and 7,000 years ago. The semi-nomadic peoples that settled this land used oases like Hatta, Liwa and Al Ain to establish agricultural hubs. Because of the unforgiving climate, survival depended on meticulous water management. Spurred by water scarcity, these early communities enforced strict punishments for anyone who intentionally or inadvertently jeopardized the essential water resources.
Around 3,000 years ago, in the late Bronze Age, the first Aflaj were developed in Hatta and Al Ain oasis. These underground aqueducts convey water from springs or wells to the demand areas by gravity flow. The groundwater use had an apparent social context: The maintenance of community-owned infrastructure was the responsibility of all shareholders. Governance systems ensured that the water was properly divided among the different users, and that the cleanest water at the entry point of the water into the oasis was available as drinking water for everyone. Springs and oases were places of flourishing community life and became targets of militant conflicts.

The main aquifers in the United Arab Emirates include the limestone aquifers in the north and east, fractured ophiolite rocks in the east, gravel aquifers flanking the eastern mountain ranges on the east and west and sand dune aquifers the south and west.

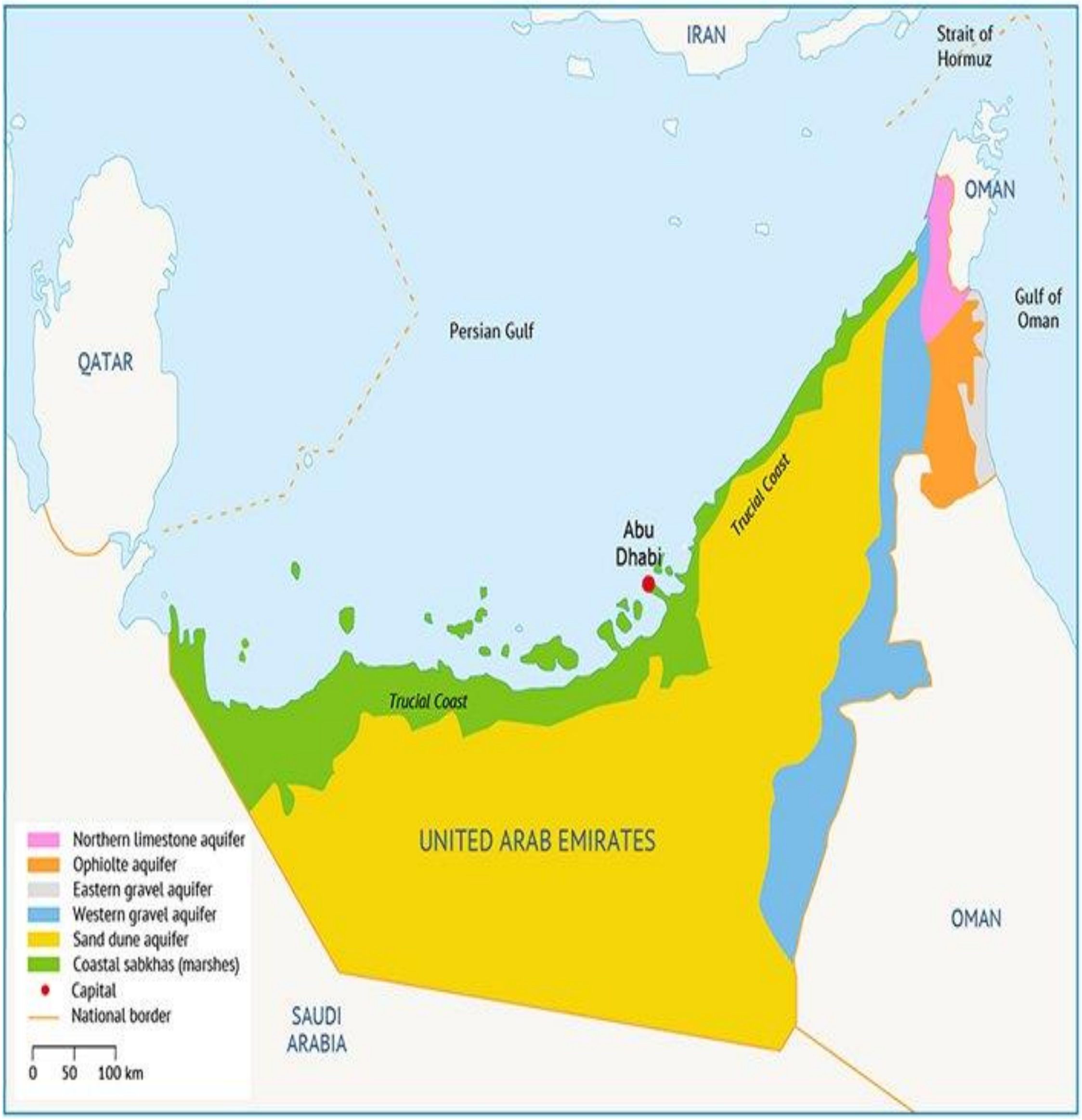


Figure 2. Main Aquifers in United Arab Emirates

Groundwater quality in the shallow and deep aquifer systems, particularly in the Hatta region, ranges from 600 to 2000 parts per million (ppm). Household water quality is considered one of the best in the world, reaching 96%. Groundwater accounts for 44% of the total used water resources. There was a significant drop in groundwater levels of about 10 metres per decade until the mid-1990s, and 70 metres since then. The UAE is currently using groundwater reserves more than 20 times faster than they can be recharged.

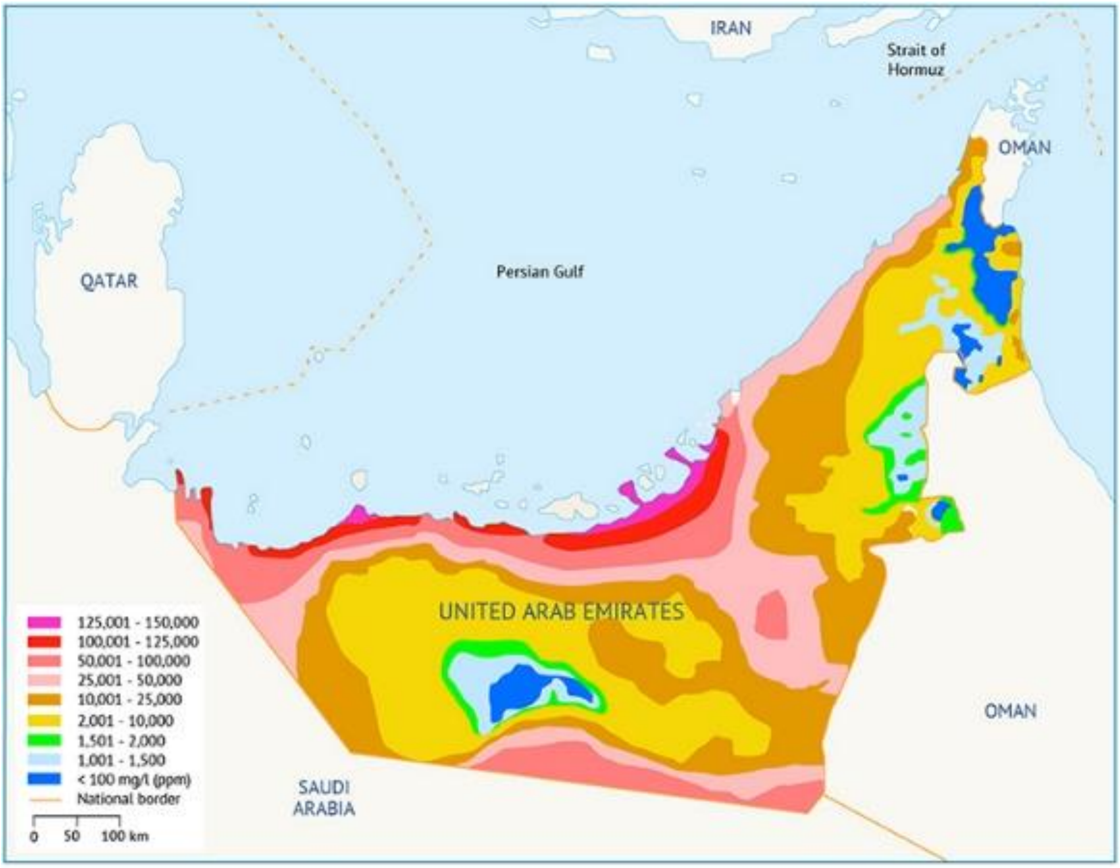


Figure 3. Groundwater salinity across the UAE

Even though, the dams in the UAE are small, they are critical for water supply and enhancement of groundwater quality. Hatta Dam for example is one of the most important dams in Dubai which is located relatively high in the Hajar Mountains.

The First and Second Hatta Dams that were built at a cost of $25 million have a total storage capacity of around 20MCM of rainwater. It is traditionally considered the ultimate families' destination in the summer to escape the heat and humidity of the coast.

Materials and Methods

The water resources of Dubai face severe depletion and quality deterioration. Similarly, farms find themselves lacking in good irrigation water quality and consequently face salinization of their soil resources. This has led to widespread temporary fallow (40%) of farmlands. Dubai Municipality compiled the Soil Salinity Map of Dubai Emirate in 2018, reflecting the natural soil conditions. During the Groundwater Well Inventory and Soil Salinity Mapping project 2015 -2018, additionally 16,000 samples were taken on more than 4,000 different farms. The soil salinity of farm soils is significantly higher than the salinity of neighbouring unaltered soils of same origin. About 80% of the irrigated land is affected by soil salinity to a varying degree. The Soil salinization is the result of:

- Low rainfall to wash out natural salts from the soil (arid climate)
- Use of brackish groundwater for irrigation

- Soils, which prevent free drainage of water and leaching of salts: loamy texture, hardpan layers, man-made soil compaction
- Poor on-farm water management (too low or excess irrigation)
- Excess irrigation is applied to control soil salinity (leaching), but using the frequently brackish groundwater, limited effects can only be achieved.

ModeflowMap as an enterprise GIS Solution is not used only during 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 where targeted users are not only Government entities such as environment agencies, municipalities, agriculture departments…etc. But also, scientists and researchers that are interested to the groundwater modelling and analysis. The figure summarizes also the different Geodatabase created for this project such as soil types' database, High Resolution Satellite images mosaics, Agriculture, Land Use, and Meteorology…. etc.

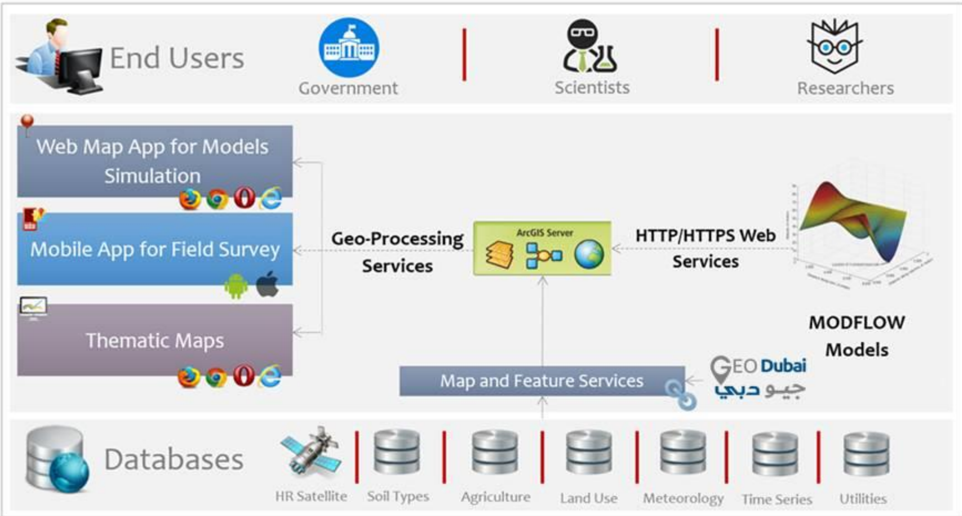


Figure 4. ModeflowMap Main Components (Models, Mobile and Web, Databases, End Users for profile management)

As a first step towards achieving such goal, the Identification of technical and functional requirements was critical and was reported as a System Requirement Study Document. This document identifies the data and functional requirements for all of the intended system components based on a comprehensive research about the gaps in actual scenarios of groundwater resources management. The second step was about preparing a scalable data model easy to change without affecting the developed solutions. This model was designed using UML2.0 Standard.

The third step was the most challenging of all (Data Collection), many reasons are behind these challenges:

- Required conversion of paper maps to spatial data is a long manual process
- Non conformity of spatial datasets in terms of spatial reference, extent and positional accuracy
- Missing information/ attribute data in several datasets
- Missing metadata in 90% of available spatial datasets
- Access Rights to some datasets took very long time to be granted
- Options to share high resolution multidate satellite images are very limited
- Not available information for many areas to support evaluation and validation processes.

The analysis and processing are two steps where ETL (Extract, Transform and Load) was used, automated workbenches had been developed to georeference, adjust, load and update datasets from different data sources.

The development phase involved multiple platforms, since ModeflowMap has multiple components: ArcGIS API for Javascript, QT code for cross platform mobile development and HTML 5 for user interface and user experience.

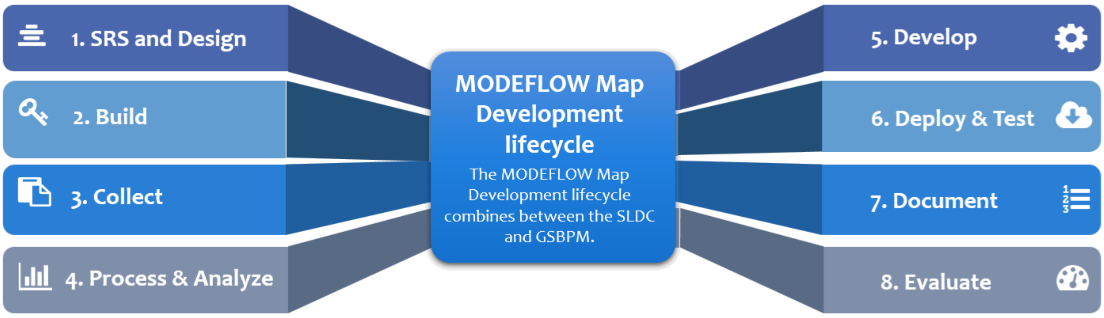


Figure 5. ModeflowMap Implementation Lifecycle

Data Description

ModeflowMap requires different types of inputs: raster, vector and alphanumeric, to be managed by shared desktop-GIS, web-GIS and Mobile-GIS environments. Mainly, the solution combines data from: satellite platforms, field agronomic inspections, cadastre and information about irrigation rights, among others. This paper will describe mainly the field data inspection variables and datasets.

Agronomic data collection information

Dubai Municipality is the first to use the ModelfowMap Mobile-GIS Solution to collect groundwater well information including the following:

- Unique ID of the well,
- Longitude and Latitude of the Well,
- Facilities available along with asset barcodes,
- Water quality level,
- Well Type
- Well Depth
- Water Depth
- Well Dimensions
- Casing Material
- Volume of Water per well volume
- Tubing Material
- Pump set
- Weather Conditions
- Volume pumped during sampling
- Pumping rate during sampling
- Dissolved Oxygen (DO) in mg/l
- Specific Electrical Conductance (µS/cm)
- Oxidation-reduction potential (ORP)
- Turbidity (NTU)
- PH Value
- Temperature (C)
- Notes
- Sketch on Picture or Map
- Photos

This spatial data is managed and stored within an enterprise Geodatabase (Oracle 12g) and administered through ModeflowMap Web-Module. Therefore, ModeflowMap desktop, Web and Mobile environments have all allowed an automatic generation of reports including agronomic information and cartographic maps to assist management and monitoring of inspections in real-time.

Cadastral Parcel Information

The GIS Centre at Dubai Municipality showed a great support to this study by providing available spatial datasets that allowed us to identify all allocated plots for cultivation and their relevant cadastral information. These datasets are critical to register and classify irrigated plots, with or without rights for irrigation within ModeflowMap.

Figure 6. Example of cadastral Map – A AWIR DUBAI

Complementary Data Sources

Multiple complementary data sources are very helpful to interpret analyse and visualize results. Especially, land use vector layers with information about the basin demarcation, urban centres, and locations of the basin to be inspected by the concerned departments, areas with specific irrigation features and areas with limitations were also identified. In addition, the most recent orthophotos from Dubai Municipality were provided by the GIS Centre to compare results and have better overview of the thematic maps and reports. The GIS Centre provided also sensitive information about boreholes and reports relevant to soil types in order to study and interpret some variance parameters between soil information and groundwater quality. Other Layers were used for navigation purposes, such as Landmarks, Points of Interest, Network Dataset, Makani Entrances, Zoning, Communities, Major Projects…etc.

Since Basemaps are necessary for the ModeflowMap Mobile component, English and Arabic Basemaps had been requested and granted to be used from the GeoDubai Committee.

Figure 7. Complimentary data sources and Layers

Desalination Plants

Farmers in the surveyed areas use water from desalination plants instead of the groundwater due its high salinity compared to irrigation requirements. In total, 187 desalination plants were identified as supply resource of fresh water to crops and livestock. Figure 8 shows the distribution and relative percentage of the desalination plants in the surveyed areas. Water supplied to desalination plants on site ranges from 1,400 to 37,400 μS/cm.

Figure 8. Distribution of the desalination plants

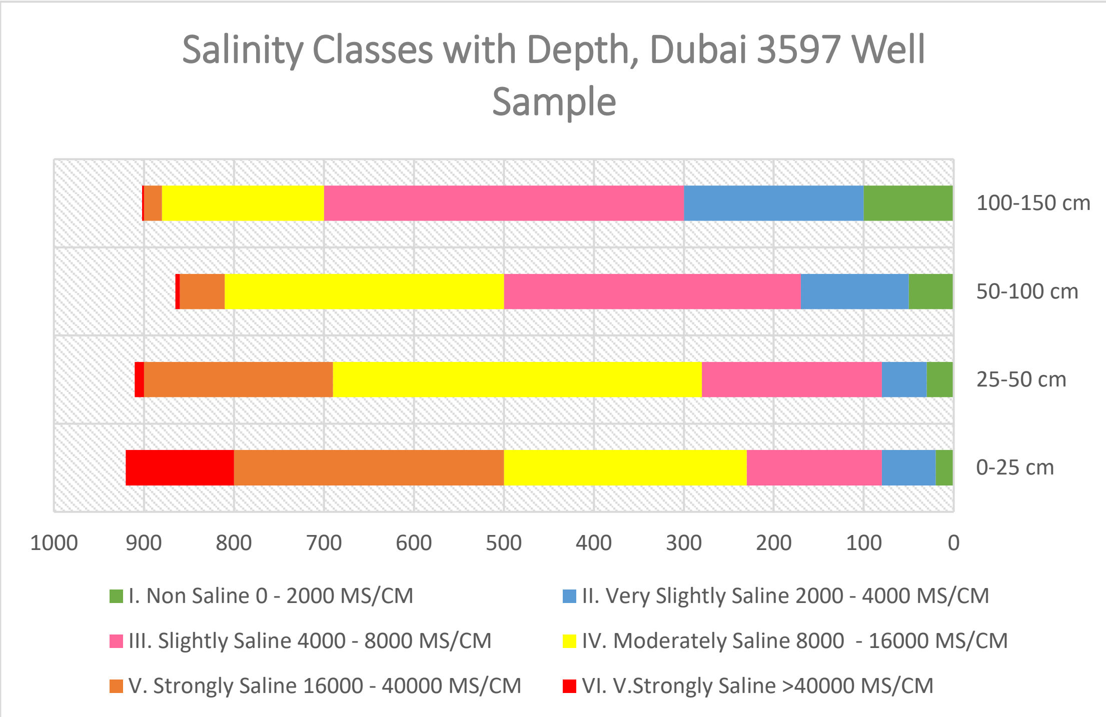


Figure 9. Salinity distribution at 4 standard depths for soils of 3597 selected well samples

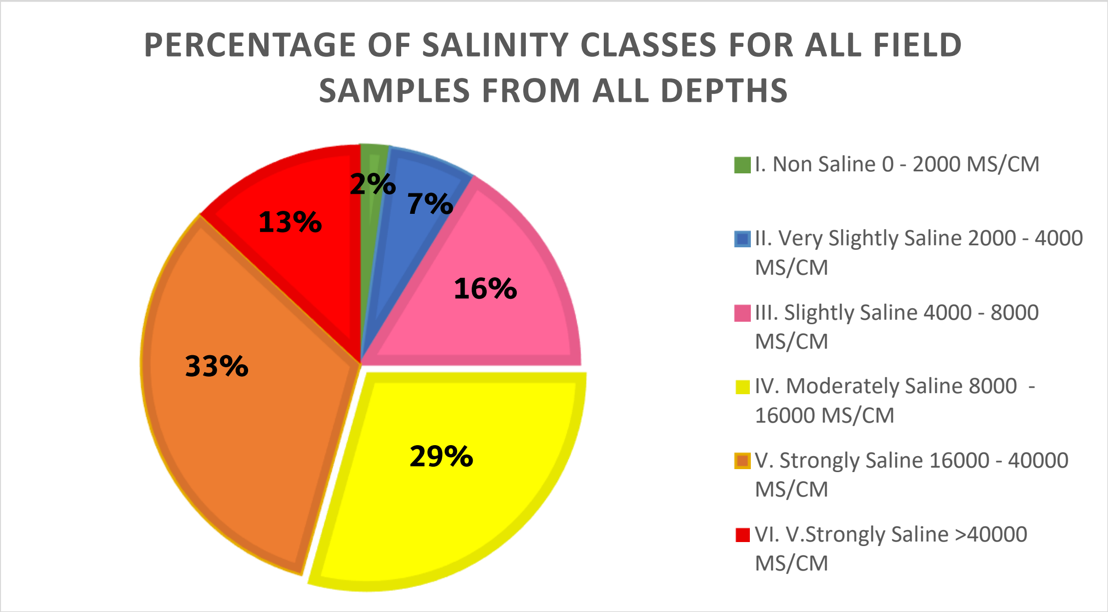


Figure 10. Percentage of salinity classes for ALL field samples from all depths.

The preliminary interpretation of the collected and processed data indicates that salinity distribution varies with depth and type of the soil profile encountered.Hatta region for example contains middle class salinities due to the presence of well-drained sandy soils mixed with drainage impeding mainly calcareous soils.

Monitoring

The objective of well salinity monitoring is to put the dynamics of well and farm soil salinity into perspective to the deterioration of irrigation water quality in order to develop a nationwide concept in how to optimize available water and soil resources. The monitoring plan establishes a baseline on the behavior of soil, helping to establish key performance indicators for a future management program to be implemented.

In general, a monitoring well should not be dry and can be cultivating irrigation resource for perennial or annual crops, which is representative of the soil landscape.

All regions whose water source can be readily accessed and measured quantitatively and qualitatively are considered important for this survey. Furthermore, wells should be:

- Equally distributed geographically through the agricultural regions
- Representative of groundwater conditions and soil
- Representative of cultivation type: falaj, oasis, farm permanent crop, farm annual crop…etc.
- Representative of Irrigation type: drip irrigation, sprinkler, flood irrigation…etc,
- Representative of all types: canal, pipeline, recycled wastewater
- Representative of farm size

In order to manage the monitoring activities, ModeflowMap Mobile module was used as described in the sections below:

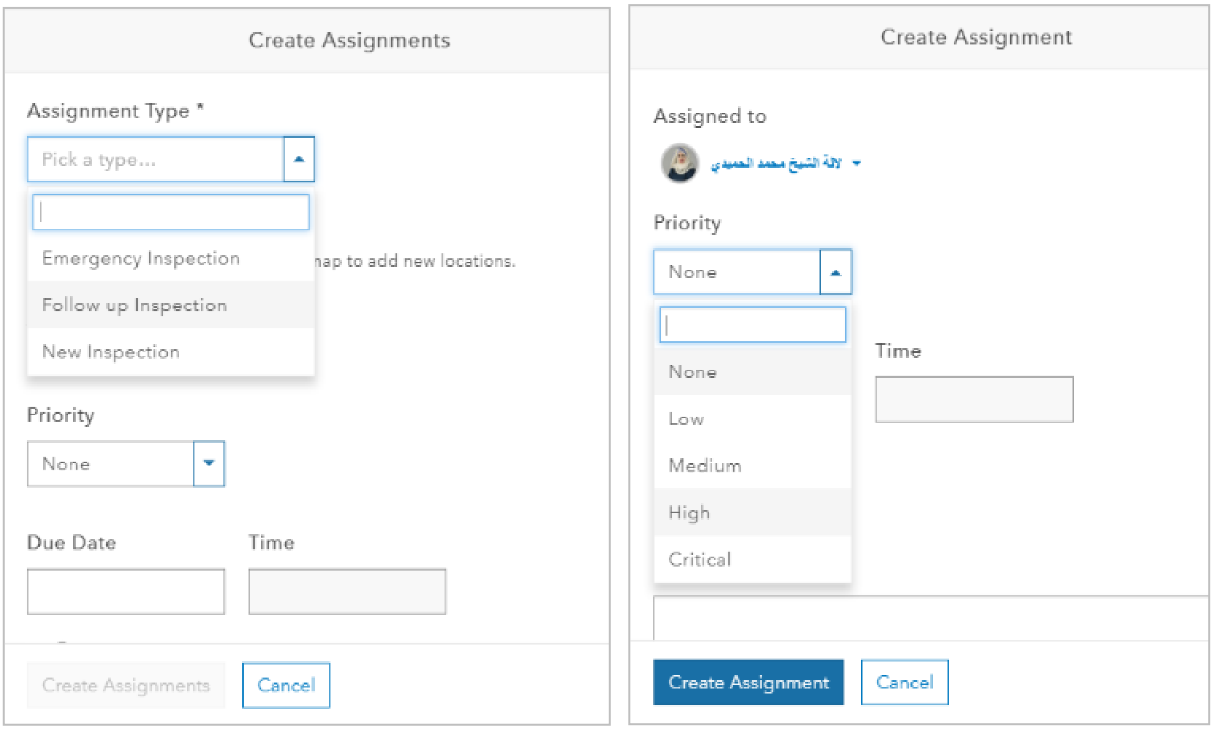
Field Work Assignment

ModeflowMapwas used toplan for the mission of surveys triggred by the sampling design process; which is performed using multiple methodologies (simple random sampling, or stratified, or selection on map of priority areas).

Thanks to the field work assignment module, Dubai Municipality was able to increase the productivity of their field teams, shrink response times especially in remote areas such as Hatta, lower the costs of data entry manpwer, and consequenty improve overall inspection process. This module enables connecting the office and inspectors with the information and processes they need to service also the farmers and the scientists who need to remodel the groundwater conditions of aquifers using up to date information.

The user interface of the field assignment module gives the opportunity to create missions/ assignments of types:

- New Inspection/ Survey
- Follow up Survey



- Emergency Survey

Figure 11. ModeflowMap Mobile Module- Field Work Assignment

It gives also the planner or the supervisor the option to choose how important the assignment is, its deadline and who should perform it. It also shows the location on the map along with search engine for places. Each field worker will receive on his smartphone or device the assigned tasks along with details and attachments if uploaded by the planner. The dispatchers can be one or multiple based on the settings created previously. The planners can track each field worker, and also check its status and completion status of his/her assignments.

Task Acceptance and Feedback

Through ModeflowMap interface, the field workers could complete their work assignments or tickets, review the tasks history, manage their itinerary, access critical information about the wells to inspect any time, from any deviceand also prioritize missions and retrieve feedback from controllers and supervisors based on prepared priority plan, or emergency or complaints of well owners.

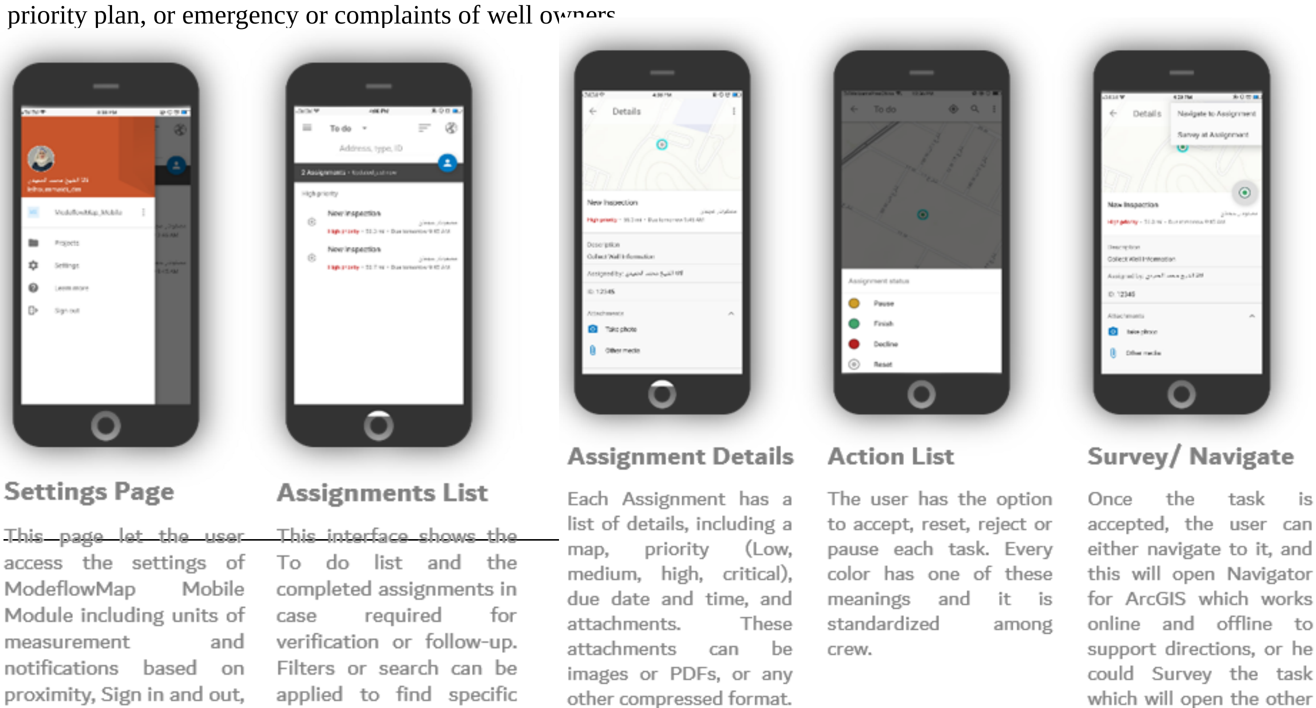


Figure 12. ModeflowMap Mobile Module- Task Acceptance and Feedback

Smart Field Data Collection

This module of ModeflowMap however is the core of the survey process, it supports the field data collection Information at the location of the Well and it includes field data capturing, scan asset's QR codes, pre-populate answers, and measure well's depth and dimensions using Spike laser device.

ModeflowMap V1.0 allowed a 100% transformation from paper and spreadsheets to an interactive mobile app that work seamlessly without an internet connection, which is very important especially in remote areas, its form of data collection is smart and dynamic, it changes according to the user selections, location, and task, as well as observed conditions of the well. Such feature is critical to avoid human errors during the collection phase which impacts the spatial data quality.

Moreover, the codes created for categories of form selections during the inspection time supports the scientists while analyzing outputs and generating statistics or thematic maps, since there is a pre-defined standard respected and maintained by the field collection application to support the overall workflow and guarantee data quality and integrity.

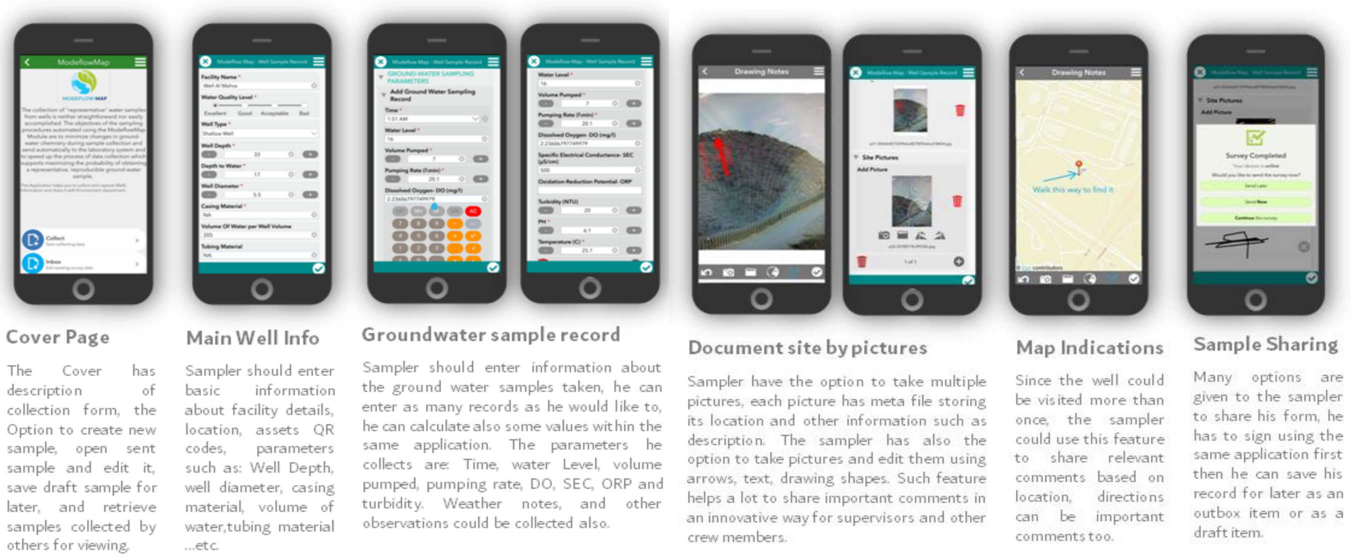
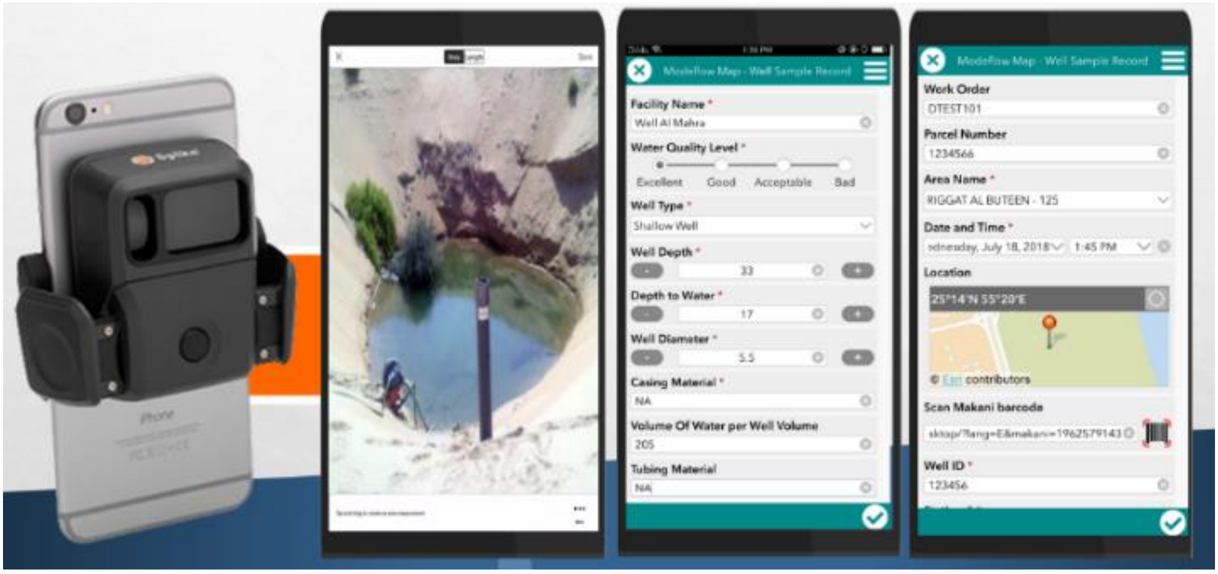


Figure 13. ModeflowMap Mobile Module- Smart Field Data Collection

ModeflowMap Mobile Module used for the wells survey is a cross platform mobile application, downloadable from both Apple Store and Play Store, easy to use and integrated database level with other ModeflowMap Modules. There is also a web version accessible from the following QR code, where field crew can access it



using any browser and it supports all functions available in the mobile version such as electronic signature, calculator, location finder…etc.

Figure 14. ModeflowMap Mobile Module- Measure Well Dimensions through laser measurement device SPIKE

Conclusions

This paper presents the results of Dubai Groundwater well survey and soil salinity field data collection using ModeflowMap, a powerful and an enterprise solution with great interest and utility for decision makers, groundwater researchers, and operations crew for water resources planning, survey and control. This Survey went through the main following stages:

Planning: Prepare and assign work orders from dispatchers and project managers usingModeflowMap Desktop and Web GIS.

Field data collection: capture well information and soil salinity parameters including measurements and validate results based on supervisors' comments and predefined forms. The field workers had other support tools including navigation to support them reach assigned sample locations and laser measurement devices to collect distance and area variables as required.

Spatial data analysis and interpretation: this phase includes the evaluation of the results and its interpretation into the required reports, maps and statistics.

Through the web-GIS interface of ModeflowMap the visualization and editing of inspection results is possible for enhancement purposes of models and forecasts. It allows also the tracking of inspectors in field and the monitoring of their performance in timely manner.

The use of ModeflowMap enabled full and streamlined integration between groundwater departments in Dubai Municipality; it allowed the optimization of scheduling and work assignment and helped gain real-time insight for operational improvements. All of above contributed to support scientists and researchers in remodelling the groundwater conditions throughout accessing updated well information.

Discussion

Given, the significance of the coordinated effort between Dubai 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 research supports 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.

References

1. Bernardi, M. &. (2016). Crop Yield Forecasting: Methodological and Institutional Aspects. Food and Agriculture Organization of the United Nations.
2. Basso B., S. U. (2014). A comprehensive evaluation of methodological and operational solutions to improve crop yield forecasting. Rome: FAO.
3. Donald, G.E., Gherardi, S.G., Edirisinghe, A., Gittins, S.P., Henry, D.A. & Mata, G. (2010). Using MODIS imagery, climate and soil data to estimate pasture growth rates on farms in the south-west of Western Australia. Animal Production Science, 611–615.
4. Calera, A. (2015). Remote Sensing for CropWater Management. Agrociencia Uruguay, Special Issue, 77.
5. Calera, A., Campos, I., Osann, A., D'Urso, G., &Menenti, M. (2017). Remote Sensing for CropWater Management: From ET Modelling to Services for the End Users. Sensors, 1104.
6. doi: http://dx.doi.org/10.3390/s17051104
7. Rizk, Z. &. (2003). Water resources in the United Arab Emirates. Developments in Water Science, 245-264. doi:10.1016/S0167-5648(03)80022-9
8. Saaty, T.L., 1980. The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation. McGraw-Hill, New York.
9. Saaty, T.L., 1992. Decision Making for Leaders. RWS Publications, Pittsburgh.
10. de Oliveira, Alexandre &Alencar, Nara & Gomes-Filho, Enéas. (2013). Comparison Between the Water and Salt Stress Effects on Plant Growth and Development. 10.5772/54223.
11. Liu, Y. (2016). Landscape connectivity in Soil Erosion Research: concepts, implication, quantification. Geographical Research, 1, 195–202. Manyevere, A., Muchaonyerwa, P., Mnkeni,
12. Al-Wadaey, A., &Ziadat, F. (2014). A participatory GIS approach to identify critical land degradation areas and prioritize soil conservation for mountainous olive groves – case study. Journal of Mountain Science, 11,782–791.
13. K.E.Kasapoglu, M.N.Toksöz. (1983). Tectonic consequences of the collision of the Arabian and Eurasian plates (1983). Finite element models. Tectonophysics Volume 100, Issues 1–3, December 1983, Pages 71-95.
14. Laflen, J. M., & Flanagan, D. C. (2013). The development of U.S. soil erosion prediction and modeling. International Soil and Water Conservation Research, 1, 1–11.
15. Malek, C. (2013, January 22). The National. Retrieved from Agriculture is the largest consumer of water: https://www.thenational.ae/uae/agriculture-is-the-largest-consumer-of-water-in-abu-dhabi-1.565172
16. International Center for Biosaline Agriculture–ICBA; Innovative Agriculture in Saline and Marginal Environments; 2015 [ICBA].
17. Renard, K. G., Yoder, D. C., Lightle, D. T., & Dabney, S. M. (2010). Universal soil loss equation and revised universal soil loss equation. Handbook of Erosion Modelling, 1, 137–167.
18. Ivana MesićKiš. (2016). Comparison of Ordinary and Universal Kriging interpolation techniques on a depth variable (a case of linear spatial trend), case study of the Šandrovac Field. The Mining-Geology-Petroleum Engineering Bulletin UDC: 528.9: 912.doi: 10.17794/rgn.2016.2.4
19. G. Buttafuoco, M. Conforti, P.P.C. Aucelli, G. Robustelli, F. Scarciglia. (2012). Assessing spatial uncertainty in mapping soil erodibility factor using geostatistical stochastic simulation. Environmental Earth Sciences, 66 (4) (2012), pp. 1111-1125
20. S.W. Duiker, D.C. Flanagan, R. Lal Erodibility and infiltration characteristics of five major soils of southwest Spain Catena, 45 (2) (2001), pp. 103-121.
21. Paroissien J.B., Darboux F., Couturier A., Devillers B., Mouillot F., Raclot D., Le Bissonnais Y. (2015). A method for modeling the effects of climate and land use changes on erosion and sustainability of soils in a Mediterranean watershed (Languedoc, France). Journal of Environmental Management 150 (2015) 57-68.
22. Roose, E. (1976) Use of the Universal Soil Loss Equation to Predict Erosion in West Africa. In: Soil Erosion: Prediction and Control, SCSA, Special Publication No. 21, 60-74.
23. Mohsen Sherif, Mohamed Almulla, Ampar Shetty, Rezaul K. Chowdhurya (2014). Analysis of rainfall, PMP and drought in the United Arab Emirates. INTERNATIONAL JOURNAL OF CLIMATOLOGY. Int. J. Climatol. 34: 1318–1328.
24. Al-Rashed MF, Sherif MM. 2000. Water resources in the GCC countries: an overview. Water Resources Management 14(1): 59–75.

25. M, Ramachandra &Kottala, Raghu ba& M, Rajasekhar &Badapalli, Pradeep. (2019). Lineament Analysis by Remote Sensing and GIS Techniques for Groundwater and Mineral Exploration in and around Lingala and Pendlimarri Mandal's of Kadapa District, A.P, India.
26. Food and Agriculture Organization of the United Nations. SOIL EROSION: the greatest challenge for sustainable soil management.
27. Alam, Afroz. (2014). Soil Degradation: A Challenge to Sustainable Agriculture. International Journal of Scientific Research in Agricultural Sciences. 1. 50-55. 10.12983/ijsras-2014-p0050-0055.
28. Crosson, Pierre & Pimentel, David & Harvey, Celia &Resosudarmo, Ida & Sinclair, K & Kurz, D & McNair, M &Crist, S &Shpritz, L & Fitton, L &Saffouri, R & Blair, R. (1995). Soil Erosion Estimates and Costs. Science. 269. 461-465. 10.1126/science.269.5223.461.
29. Oldeman, L.R. &Hakkeling, R.T.A. &Sombroek, W.G. (1991). World map of the status of human-induced soil degradation: an explanatory note, 2nd. rev. ed.
30. Mikola, Peitsa. (1979). The role of forestry in the fight against desertification. Silva Fennica. 1979. 13(3): 223-226. 13. 10.14214/sf. a14895.
31. TizianoGomiero. Soil Degradation, Land Scarcity and Food Security: Reviewing a Complex Challenge. Sustainability 2016, 8, 281; doi:10.3390/su8030281.
32. Business, G. (2016). Retrieved from https://gulfbusiness.com/uae-eyes-man-made-mountain-to-maximise-rainfall/
33. Hassam Nasarullah Chaudhry, M. N.-W. (2018). Temperature analysis and the effect of urban development on the outdoor thermal comfort and intensification of the Urban Heat Island phenomenon in the United Arab Emirates. Windsor Conference.
34. International Center for Biosaline Agriculture–ICBA. (2015). Innovative Agriculture in Saline and Marginal Environments. Dubai: ICBA.
35. Prasad, R.K., Mondal, N.C., Banerjee, P., Nandakumar, M.V., Singh, V.S., 2008. Deciphering potential groundwater zone in hard rock through the application of GIS. Environ. Geol. 55, 467–475.
36. Rao, Y.S., Jugran, D.K., 2003. Delineation of groundwater potential zones and zones of groundwater quality suitable for domestic purposes using remote sensing and GIS. Hydrol. Sci. J. 48 (5), 821–833.
37. Machiwal, D., Jha, M.K., Mal, B.C., 2011. Assessment of groundwater potential in a semi-arid region of India using remote sensing, GIS and MCDM techniques.
38. Water Resour. Manage. 25, 1359–1386. Mukherjee, S., Gupta, M., Srivastava, P.K., 2012. Mapping spatial distribution of pollutants in groundwater of a tropical area of India using remote sensing and GIS. Appl. Geomat. 4, 21.
39. Fashae, O.A., Tijani, M.N., Talabi, A.O., Adedeji, O.I., 2014. Delineation of groundwater potential zones in the crystalline basement terrain of SWNigeria: an integrated GIS and remote sensing approach. Appl. Water Sci. 4,19–38. doi: https://doi.org/10.1007/s13201-013-0127-9.
40. Singh, A.K., Panda, S.N., Kumar, K.S., 2013. Artificial groundwater recharge zones mapping using remote sensing and GIS: a case study in Indian Punjab. Environ. Earth Sci. 62 (4), 871–881. doi: https://doi.org/10.1007/s00267-013-0101-1. ISSN0364-152X.
41. Andriolo et al., 2005 J.L. Andriolo, L.D. Gean, H.W. Maiquel, D.S.G. Rodrigo, O.C.B. Gis Growth and yield of lettuce plants under salinity Hortic. Bras., 23 (4) (2005), pp. 931–934.
42. Bayuelo Jimenez et al., 2002 J.S. Bayuelo Jimenez, D.G. Debouk, J.P. Lynch Salinity tolerance in phaseolus species during early vegetative growth Crop Si., 42 (2002), pp. 2184–2192.
43. Beltagi et al., 2006 M.S. Beltagi, M.A. Ismail, F.H. Mohamed Induced salt tolerance in common bean (Phaseolus vulgaris L.) by gamma irradiation Pak. J. Biol. Sci., 6 (2006), pp. 1143–1148.
44. Cachorro et al., 1995 P. Cachorro, R. Martinez, A. Ortiz, A. Cerda Abscisic acid and osmotic relations in (Phaseolus vulgaris L.) under saline conditions Plant Sci., 95 (1995), pp. 29–32.
45. J. Cheruth, G. Ragupathi, K. Ashot, M. Paramasivam, S. Beemarao, P. Rajaram
46. Interactive effects of triadimefon and salt stress on antioxidative status and ajmalicine accumulation in Catharanthus roseus Acta Physiol. Plant., 30 (3) (2008), pp. 287–292.
47. Dantus et al., 2005 B.F. Dantus, L. Ribeiro, C.A. Aragao Physiological response of cowpea seeds to salinity stress Rev. Bras. Sementes., 27 (1) (2005), pp. 144–148.
48. Etherton, 1963 B. Etherton Relationship of cell transmembrane electropotential to potassium and sodium accumulation ratios in oat and pea seedlings Plant Physiol., 38 (1963), pp. 581–585
49. Jamil et al., 2005 Jamil, M., Lee, C.C., Rehman, S.U., Lee, D.B., Ashraf, M., Rha, E.S., 2005. Salinity (NaCl) tolerance of brassica species at germination and early seedling growth. Electronic J. Environ. Agric. Food Chem., ISSN: 1579–4377.
50. K. Kapoor, A. Srivastava Assessment of salinity tolerance of Vinga mungo var. Pu-19 using ex vitro and in vitro methods Asian J. Biotechnol., 2 (2) (2010), pp. 73–85.

51. Karen et al., 2002 W. Karen, R.Y. Anthony, J.F. Timothy Effects of salinity and ozone, individually and in combination on growth and ion contents of two chickpea (Cicer aritinum L.) varieties Environ. Pollut., 120 (2) (2002), pp. 397–403.
52. Memon et al., 2010 S.A. Memon, X. Hou, L.J. Wang Morphological analysis of salt stress response of pak Choi EJEAFChe, 9 (1) (2010), pp. 248–254.
53. Misra et al., 1997 A. Misra, A.n. Sahu, M. Misra, P. Singh, I. Meera, N. Das, M. Kar, P. Sahu Sodium chloride induced changes in leaf growth, and pigment and protein contents in two rice cultivars Biol. Plantarum, 39 (2) (1997), pp. 257–262.
54. Mustard and Renault, 2006 J. Mustard, S. Renault Response of red-osier dogwood (Cornus sericea) seedling to NaCl during the onset of bud break Can. J. Bot., 84 (5) (2006), pp. 844–851.
55. Qin et al., 2009 J. Qin, W. Dong, K. He, J. Chen, A.Z. Wang Short-term responses to salinity of seabuckthorn (Hippohaerhamnoides L.). seedlings in the extremely cold and saline Qinghai region of China For. Stud. China, 11 (4) (2009), pp. 231–237.
56. Raul et al., 2003 L. Raul, O. Andres, L. Armado, M. Bernardo, T. Enrique Response to salinity of three grain legumes for potential cultivation in arid areas (plant nutrition) Soil Sci. Plant Nutr., 49 (3) (2003), pp. 3