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Geospatial Analysis Of Groundwater Quality In Dubai

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Abstract—Dubai's groundwater wells have become at risk of contamination, over-extraction, and over-irrigation for the past two decades. Thus, the declining water quality and modest irrigation practices in many areas pressured farmers to install packaged desalination equipment that caused a significant increase in the salinity levels of the groundwater, leading to contaminants percolation to the aquifers.

This project explores the possibilities of using geospatial analytics such as Nearest Neighbour and Regression Analysis to model and predict water levels. Such data is essential for the understanding and resolution of many complex water resources issues commonly faced by hydrologists, water-supply managers, engineers, regulatory agencies, and the public.
It also features ModeflowMap;an innovative Enterprise GIS Solution developed tocollect groundwater quality parameters, including the water level. This toolwas the primary solution used to collect groundwater data for47,433 wells and boreholes in Dubai. Itwas designed as a preliminary effort to store the records relevant to the quality, quantity, biological, and chemical properties, as well as the type and location of groundwater resources. Such data helped track and analyze the status and uses of groundwater reserves. Furthermore, the findings assisted in improving and promoting the efficient use of water resources in the Emirate.
Such comprehensive effort is mandatory to fully understand the state of the groundwater resources in the Emirate and support the development of effective policies tomanage these resources efficiently.

Oneof the key purposes of this study is to highlight the importance of groundwater level measurementsasa fundamental indicator of the status of thisresource and to foster a more comprehensive approach to the long-term collection of these essential data.

Keywords: groundwater monitoring, Geospatial Analysis, Groundwater modeling, groundwater well inventory, water salinity mapping, ModeflowMap, thematic maps, Dashboards.

1. INTRODUCTION

According to the United Nations , a country is defined as 'water scarce' if it has 1000 cubic meters or less of water available per capita per year. The United Arab Emirates's natural water supply doesn't reach half this level, making it one of the world's most water-scarce nations [1].One of its most populous cities with more than three million people, Dubai relies primarily on the desalination plants, which consists 98.8 percent of its water supply [2]. In comparison, most of the groundwater in the UAE is found in fossil aquifers that receive little to no waterrecharge. For every liter of water flowing into the country's groundwater reservesfrom infrequent rainfall, twenty-five liters is withdrawn. This extraction rate leads tosevere degradation of the remaining water supplies. Renewable water resources havedecreased by 42 percent since 2000, and further declines are expected in the near future.Therefore, acute water shortages are expected in the region by 2025 [3].

Over-consumption is also a problem in the water sector. The UAE is the world's third-largest consumer of water, despite its arid climate and lack of renewable water sources. Consumers in the UAE use around 400 liters of water each day, compared to a global average of 250 liters. The UAE relies on its expensive desalination plants to meet this water demand [3].

Moreover, groundwater accounts for up to 94 % of water consumption in the agriculture sector in some emirates like Dubai and Abu Dhabi. Nonetheless, the current usage of groundwater reservoirs exceeds the natural recharge rates by more than 15 times. Additionally, the Food Sustainability Index (FSI) ranked the UAE at the bottom of 34 countries for sustainable agriculture in 2017, with the high use of dwindling resources in aquifers as a critical factor [4].

Furthermore, studies of existing productive wells concerning lithology and structures are minimal. Selection of well locations forgroundwater supply used to heavily rely on traditional field studies using existing waterpoint sites as guidelines. In general, a systematic approach to groundwaterexploration was also lacking. This research aims to contribute towardssystematic groundwater analysis utilizing remote sensing, field data collection, DigitalElevation Models (DEM), and Geospatial Analysis using Geographic Information Systems (GIS),assistingtheassessment of groundwater resources in the UAE.

Therefore, ModeflowMap is introduced in this paper, an innovative enterprise GIS Solution comprising several modules that cover essential requirements for a better understanding of groundwater conditions. This enterprise solution controls the field data collection operations, processes high-resolution remote sensing images, extracts vector data layers, ensures data quality control, enables advanced geospatial analytics, and disseminates the results in the form of thematic maps and dashboards. Consequently, it supports monitoring groundwater uses in agriculture in real-time. This solution also supports government entities as a decision support tool, including all actors involved in water management and water policy-makers at the field level.

2. MATERIALS AND METHODS

2.1 Study Area

The primary groundwater resources are available in the aquifers located in the Bajada region, in the eastern part of the country. These aquifers consist of alluvial fan deposits along the base of the RAK mountains extending over a large area. The upper aquifer is made of gravel, sand, and silt, while the lower aquifer is mainly composed of dolomite, limestone, and marl. Both aquifers vary in thickness from 200 to 800 meters. Moreover, the Dammam and Umm er-Radhuma aquifers contain highly saline water extending into the western desert regions [5].

The recharge of the shallow aquifers depends primarily on the infrequent rainfall events along with the surface run-off and hence may vary considerably from year to year. In addition, due to the high evaporation rate and surface water run-off in hilly areas, only 10 to 14% of the total precipitation could percolate to recharge the shallow groundwater aquifers[6].

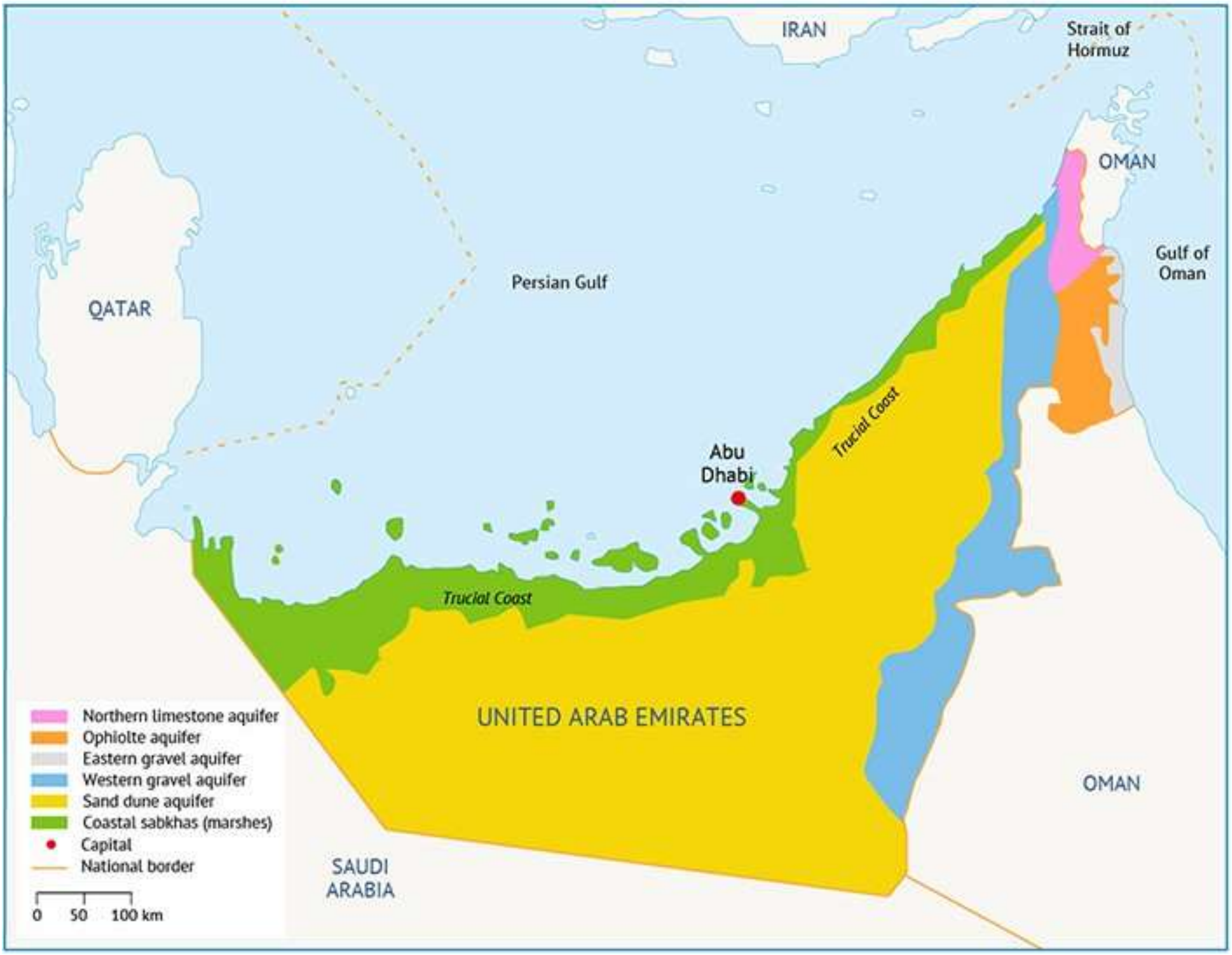


Fig 1. Principal Aquifers in United Arab Emirates [7]

In recent years, Dubai'saquifers' conditions have improved thanks tothe measures taken to achieve maximum overall cycle efficiency for all groundwater uses, including reducing groundwater abstraction to sustainable levels. However, full recovery will take decades. In addition, a comprehensive set of actions for sustainable groundwater management have been adopted, notably establishing robust monitoring and regulatory programs to conserve traditional water systems such as aflaj [8].

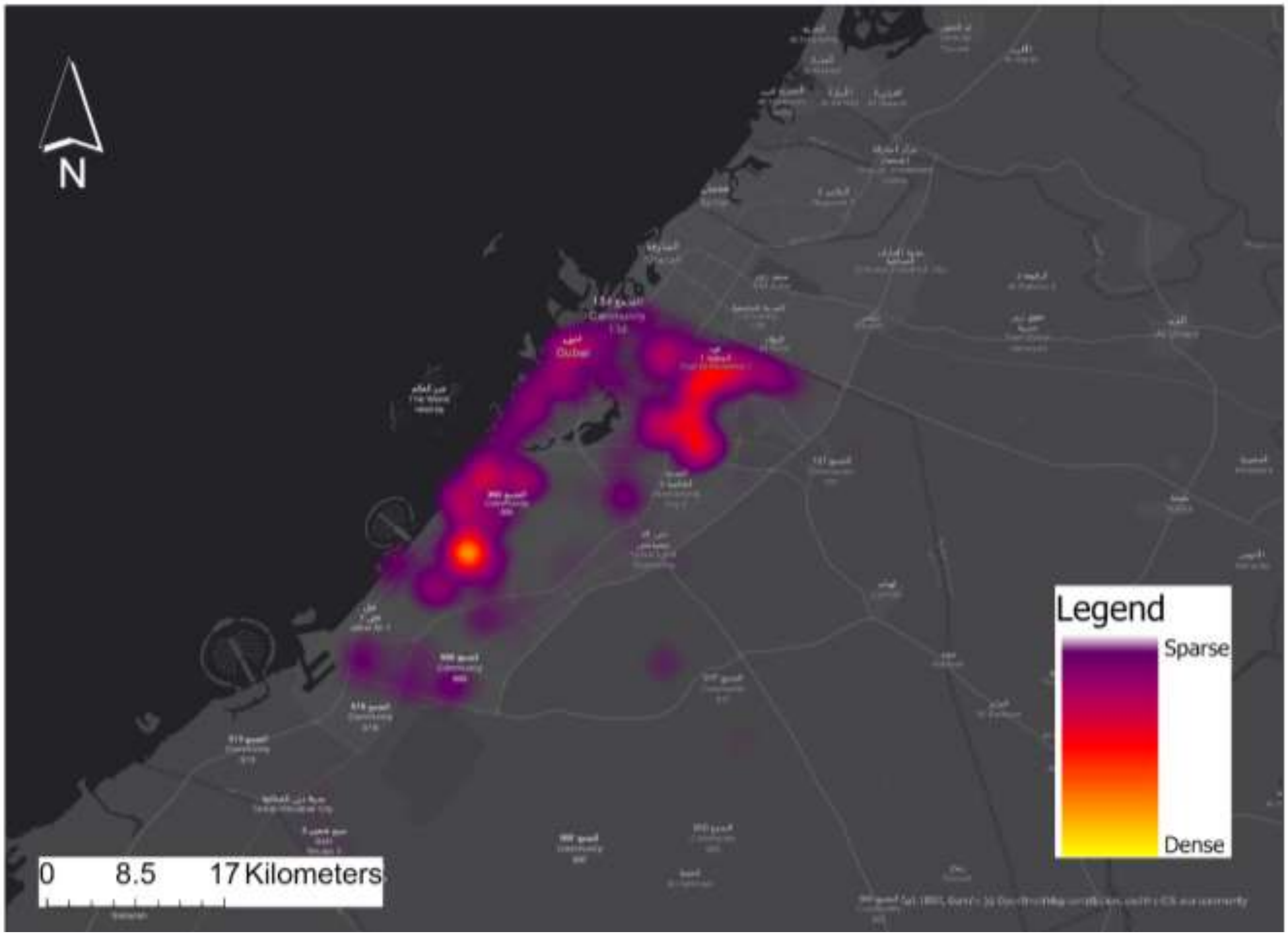


Fig. 2- Dubai Wells Distribution – Heat Map

Fig.2 represents a spatial distribution of wells density in the Dubai Emirate. The total records used for this study are 47,433.

2.2 Research Methodology

A robust methodology is essential to process all the heterogeneous data inputs efficiently and accurately, particularly the high-resolution remote sensing imagery acquired for automatic generation of the vegetation cover in the study area.An overview ofthe methodology followed in this research is summarized in the flow chart illustrated in (Fig.3). This paper focuses on the Wells and Soil inventories along with the elevation and vegetation cover maps.

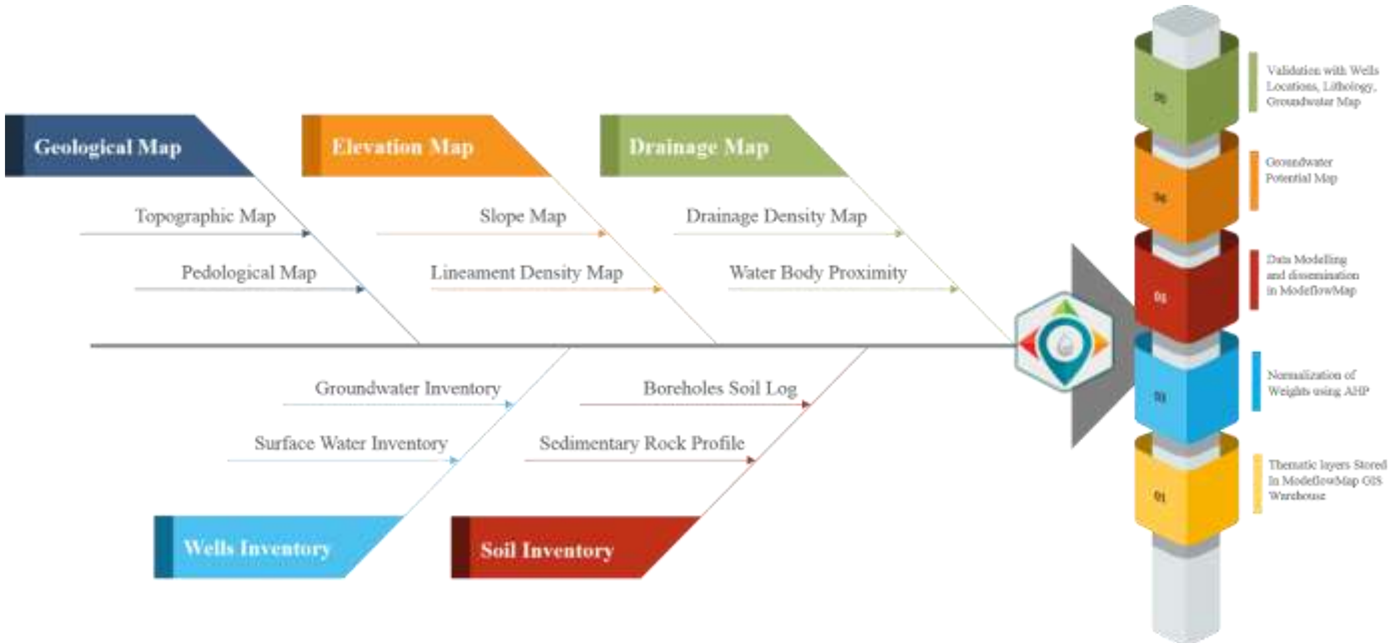


Fig.3- Flowchart summarizing the process followed for the study

This project wascarried for an overall period of 32 months and was conducted in six main phases, including the inventory of groundwater wells and soil salinity surveys. During the first phase, all the wells were assigned a unique identifying number; then, the main groundwater parameters were recorded such as pumping rates, groundwater levels, salinity, condition, and the purpose for which each well is being used. The second phase included updates to the available soil salinity data. The soil samples were taken using a frame of 2,000 farms in Dubai and then analyzed to identify the soil type, salinity, and quality. Such data will support the development of plans that determine the sustainability of these farms and classify them according to soil quality levels.

In its last phase, the ModeflowMap solution was used to analyze the groundwater and soil data to produce an atlas of aquifers in Dubai - the very first of its kind locally. The analysis summarizes groundwater sources based onthe quality,quantity, natural,chemical,and biological property, location, depth, and type. The outputsare displayed in the form of thematic maps, motion charts, sections, and infographics.

The following section provides a brief description of the context of the activities undertaken for the well soil salinity surveys:

– Phase 1- Mobilization of survey teams (Recruitment, awareness workshops, trainings)
– Phase 2- Collect other administrative data such as elevation, geological layers, water bodies layers, imagery…etc.
– Phase 3- Design of the GIS solution for field data collection (ModeflowMap Mobile Module)
– Phase 4-Planning and prediction, equipment purchase, and developing work procedures (data dictionaries, standard operating procedures, and quality control procedures).
– Phase 5- Actual well & farm surveys, including groundwater and soil sampling and analysis.
– Phase 6-Interpretation of survey results, the preparation of databases, maps, and the groundwater atlas.

2.3 Solution Components

ModeflowMap as an enterprise GIS Solution is currently used for several phases of groundwater resources management; including, planning, processing, analysis, archiving, dissemination and evaluation. It also features tools for automation such as the design, the collection, the geospatial analysis, and the cartography of thematic maps and charts through advanced geoprocessing python scripts. Hence, the ModeflowMap consists of components covering these requirements, including the Desktop, Web, and Mobile Modules (Fig.4).

Fig. 4- ModeflowMap Main Components (Desktop, Mobile and Web, Databases, Servers, …etc.)

2.4 Data Acquisition

2.4.1 Agronomic data collection information

During this study, ModeflowMap Mobile was used to collect groundwater well information in order to validate the results obtained by desktop application; the results of this Survey also supported calibrating the Hatta groundwater models to ensure accurate results. Furthermore, these inspections allow the collection of irrigation activities information in the crops and either change or add any relevant agronomic data, 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
- The 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

Table 1.Boreholes Sample Data featuring boreholes ID, boring date, location, ground level, water level, depth and diameter

BO No	BORINGDATE	EASTING	NORTHING	DMDGD_LEVEL	GD WATER_LEVEL	DEPTH	DIAMETER
12827	2008-08-14	490490	2768071	0	28.02	15	0.15
11651	2007-05-30	488967	2770785	30.44	22.6	30	0.15
11642	2007-05-30	488955	2770813	30.56	22.6	30	0.15
13328	2004-09-10	489250	2769778	31.07	22.55	30	0.13
11652	2007-06-07	489068	2770884	30.5	22.5	30	0.15
11617	2004-09-02	487267	2770775	29.72	22.5	29.9	0.13
11650	2007-06-06	489092	2770842	30.47	22.4	30	0.15
11653	2007-05-25	488987	2770870	30.46	22.4	30	0.15
11641	2007-05-27	488986	2770832	30.57	22.1	30	0.15
13336	2004-08-28	488317	2769271	28.22	21.5	29.9	0.13
43542	2008-04-17	489326	2771018	31.75	20	35	0.15
13322	2004-09-06	488906	2769514	28.13	20	30	0.13
43543	2008-04-17	489305	2771030	31.82	19.8	35	0.15
43544	2008-04-19	489305	2771045	31.12	19.6	35	0.15
43545	2008-04-20	489331	2771032	30.99	19.5	35	0.15

Throughout this project, 47,433 wells were visited in Dubai. Most wells are located on farms, along Dubai's tunnel, and in forests except some remote desert locations. Trained teams with experienced staff and dedicated advanced equipment were assigned to these remote locations, where off-road driving capabilities and extensive safety measures were mandatoryfor the Survey's success. For each surveyed well, more than 100 parameters werecollected.

Additionally, the operational status and the use of the wells were assessed. Groundwater level, salinity, temperature, and pH were also measured. The teams recorded pumping operation time, well discharge, and selected farm data.

Table 2.Example of Borehole readings (BH-BDT-44)

Borehole_ID	Water Level	Depth	UCS	Permeability	Soil Type
BH-BDT-44	6.32	4.5		7.02E-06	SANDSTONE
	6.32	7.5		3.51E-06	
	6.35	10.5		1.99E-06	
	6.32	12.5	2.7		
	6.28	13.5		1.65E-06	
	6.37	16.5		5.03E-06	
	6.35	19.5		2.56E-06	

	6.28	22.5		2.79E-06	
	6.33	24	1.07		
	6.32	25.5		2.62E-06	
	6.27	28.5		2.10E-06	
	6.35	31.5		1.83E-06	
	6.3	34.5	3.45	1.75E-06	
	6.32	37.5		2.13E-06	CONGLOMERATE
		39	8.91		
		40.5		4.60E-07	SILTSTONE
		43.5		9.89E-07	
		46.5		1.07E-06	
		49.5		7.44E-07	
		52.5		3.81E-07	
		55	4.05		
		55.5		2.46E-07	Congl. SILTSTONE
		58.5		2.99E-07	
		58.75	8.08		

The soil data collected for every depth was validated in the laboratory and documented at first in a metadata sheet as a PDF document. Then, a database model was designed to store this information and link it to the main wells and boreholes records through a unique ID for every soil type. Automating the electronic transformation was performed using FME Workbench [9]. Fig. 5 demonstrates the soil types recorded and validated by a local laboratory for BH-BDT-44. It confirms the depth of the sample collected, core recovery elements, thickness and description of the structure found.

Project: Proposed DS 215 Strategic Sewerage Tunnel Project Ref. No.: SD17000043 Location: Dubai,U.A.E Client: M/S. DUBAI MUNICIPALITY	Borehole No. BH-BDT-44 Sheet 2 of 6	ACES

Total Depth (m): 59 Ground Level (m): 20.612 Coordinates: N= 2,769,689.94 E= 487,093.45	Drilling Method: RC Boring Started: 11/12/17 Boring Completed: 13/12/17 Rig: RD-20 Driller: Al Dawi	Drilling Medium: Polymer Boring Dia. (mm): 140/125 Casing Dia. (mm): 136 Water Depth (m): 6.32	Core Dia. (mm): 85 Casing Depth (m): NA

Scale (m)	Samples: Type and Number	Samples: Depth (m)	SPT Field Records 0-15 (cm)	15-30 (cm)	30-45 (cm)	N Blows	Core Recovery TCR (%)	SCR (%)	RQD (%)	UCS (MPa)	Description of Strata	Depth (Thickness) (m)	Reduced Level (m)	Legend
11	CS8	10.5 - 12					93	91	51		Light brown, fine to medium, grained calcareous SANDSTONE, mild reaction with 10% HCl, partially to distinctly weathered (B/C), locally destructured weathered (D), fractures close to medium spaced, locally very closely spaced. **Note:** Non intact zone from 10.25-10.50m.	(2.00) 12	8.61	
12	CS9	12 - 13.5					97	95	49	2.7	**Very weak**, light reddish brown, fine to medium grained SANDSTONE, locally embedded with fine sand sized gypsum, partially weathered (B), fractures close to medium spaced, locally very closely spaced.			
13, 14	CS10	13.5 - 15					90	90	81			(5.00)		
15, 16	CS11	15 - 16.5					93	93	85					
	CS12	16.5 - 17					74	74	46			17	3.61	
17	CS13	17 - 18					98	96	75		Light brown, fine to medium grained, calcareous SANDSTONE, mild reaction with 10% HCl, partially weathered (B), locally unweathered (A), fractures close to medium spaced.			
18, 19	CS14	18 - 19.5					93	93	89			(3.00) 20	0.61	

Fig. 5- Soil Profile Sheet used for documenting soil information for every well/borehole

2.4.2 Image Processing of multispectral images

For best groundwater data analysis, different formats ofinputs are required, including raster, vector, and alphanumeric, to be controlled by shared desktop-GIS, web-GIS, and Mobile-GIS environments. The solution was developed to combine data from drones, field agronomic inspections, cadastre, and information about irrigation rights, among others.

This project relied on themultispectral drone imagery captured by the field team,which was used for the generation ofthe Normalized Difference Vegetation Index (NDVI) maps [10]. Such practice is essential for soil segregation from vegetation cover, differentiation between crops at different crop stages, and detection of plants under stress. Hence, it has been proven that there are strong correlations between NDVI data measured at certain crop stages and crop yield. Hence, tracking the crop growth at crucial steps helps estimate the crop yield and addresses issues early [11-12]. Table 3 lists the different levels of acquisition performance of the Trimble UX5 Drone.

Table 3. Acquisition Performance (Trimble UX5 Drone)

Resolution (GSD)	1 cm to 25 cm (4 to 99 in)
Height above take-off location (AGL)	75 m to 750 m (246 to 2,460 feet)
Absolute accuracy XY/Z (no ground control points)	down to 2 – 5 cm
Relative Ortho-mosaic/3D model accuracy	(1-2x/1-5x GSD)
Resolution (GSD)	1 cm to 25 cm (4 to 99 in)

The Trimble UX5 HP drone used during the field survey is equipped with a modified color-infrared (CIR) Sony NEX5R fitted with a 16 mm lens. On each flight day, roughly 100 ground-based normalized difference vegetation index (NDVI) measurements were collected with the Trimble Green Seeker Handheld at a constant height of 80 cm above the target, of which the center point was georeferenced to 2 cm accuracy using a Trimble R8RTK GNSS system [13]. Fig.6 shows an example of the drone outputs such as an ortho-rectified image with elevation contours.

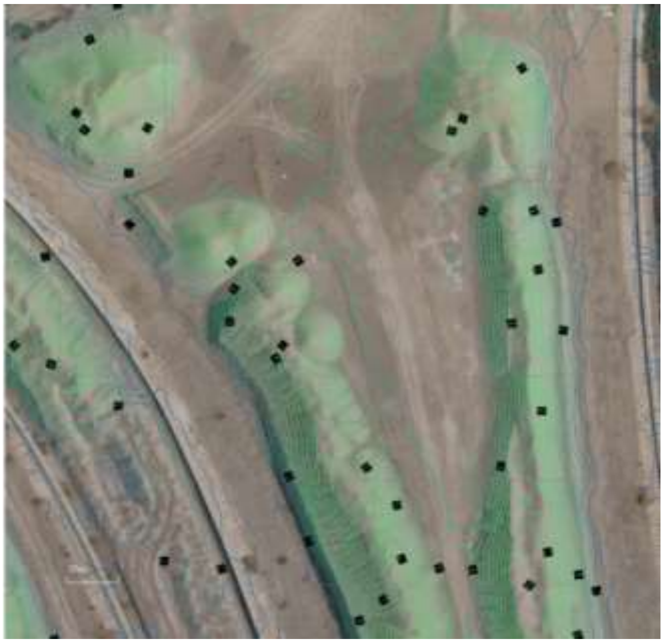


Fig. 6. Drone Mapping Output: Corrected image showing contours

2.4.3 Vegetation Cover generation

Since NDVI is considered the most widely used vegetation index to assess large agricultural lands and monitor related irrigation activities, it was integrated into theModeflowMap Desktop Module. NDVI has also been used to perform crop classification in many areas worldwide, with high accuracy of up to 90%. This index takes advantage of the contrast between the characteristics of two bands from a multispectral raster dataset; the chlorophyll pigment absorptions in the red band and the high reflectivity of plant materials in the near-infrared (NIR) band [14]. The documented and default NDVI equation is described as follows:

$$\text{NDVI} = \frac{\text{IR} - \text{R}}{\text{IR} + \text{R}} \quad (1)$$

As classification criteria, a threshold of NDVI greater than 0.2 was set. This threshold was empirically derived from matching Planet's imagery with the vegetation shapefile provided by the Dubai Municipality. Any pixel with a higher value above this threshold is considered "green" or covered by vegetation. With that, the vegetation cover percentage was calculated. This threshold was determined empirically by comparing different resulting masks with the vegetation coverage map that the GISC Centre provided. Figure 7 shows the NDVI index found for 226 communities within Dubai Emirate and classifies them into ten classes from as low as 5 percent to 45 and above percent.

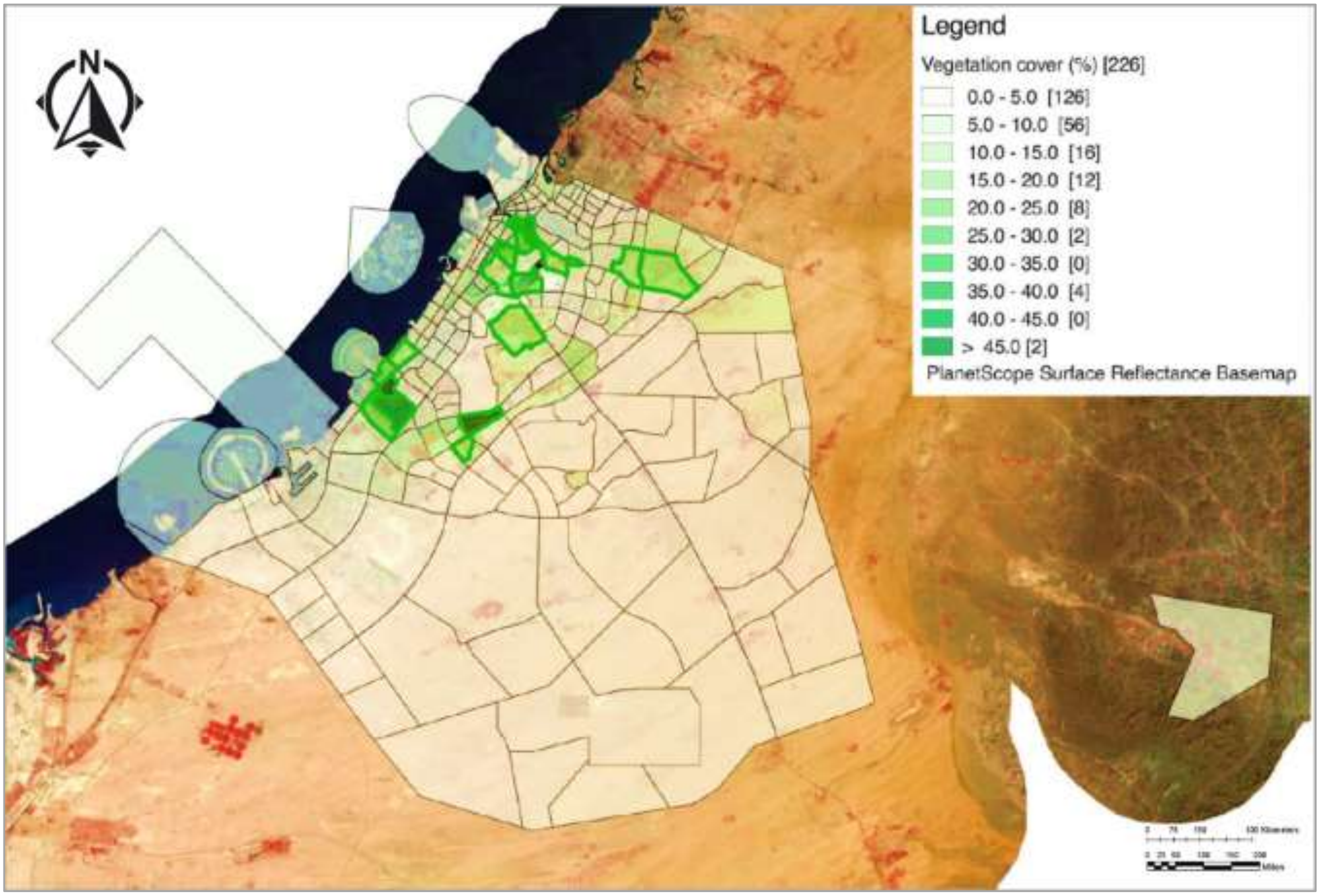


Fig.7. Vegetation cover (%) in each of the 226 Districts of Dubai and Hatta, the top 20 districts are highlighted with a green outline

Table 4. Overall Vegetation cover in October 2018

Area	Vegetation cover (%)
DUBAI (mean average)	3.10
ALL DISTRICTS (mean average)	6.60
ALL DISTRICTS (Standard Deviation)	8.32

2.5 Data Processing and Analysis

2.5.1 Nearest Neighbor

One of the most efficient and oldest distance statistics is the nearest neighbor index. It is advantageous because it is a simple tool to understand and calculate. Since two botanists developed it in the 1950s [15], it was primarily for fieldwork, but it has also been used in many fields for a wide variety of problems[16]. It was also used inseveral other distance statistics implemented in groundwater analysis and geostatistics.

In this study, the nearest neighbor index compares the distances between nearest wells and distances that would be likely expected on the basis of chance.

In order to calculate the nearest neighbor distances among the wells locations, The Average Nearest Neighbor tool on the ArcGIS Desktop was used. This tool measures the distance between each well and its nearest neighbor's location. Then, it averages all these nearest neighbor distances. When this average distance is less than the average for a hypothetical random distribution, the distribution of the analyzed wells is considered clustered. However, the wells are considered dispersed when the average distance is greater than a theoretical random distribution. Such analysis is essential for decision-makers to understand the current status of the distribution of the wells, assess the effectiveness of the drainage and irrigation systems, and take decisive actions accordingly [17].

The average Nearest Neighbor ratio is given as:

$$\mathrm{ANN} = \frac{\mathrm{Do}}{\mathrm{De}} \quad (2)$$

Where Do is the observed mean distance between each feature and its nearest neighbor:

$$\mathrm{Do} = \left(\sum_{k=1}^{n} \mathrm{dk}\right)/\mathrm{n} \quad (3)$$

And DE is the expected mean distance for the features given in a random pattern:

$$\mathrm{De} = \frac{0.5}{\sqrt{\mathrm{n}/\mathrm{A}}} \quad (4)$$

In the above equation, di equals the distance between feature i and its nearest neighboring feature. While n corresponds to the total number of features, A is the area of a minimum enclosing rectangle around all features or a user-specified Area Value.

The average nearest neighbor z-score for the statistic is calculated as:

$$\mathrm{z} = \frac{\mathrm{Do}-\mathrm{De}}{\mathrm{SE}} \quad (5)$$

Where:

$$\mathrm{SE} = 1 + \frac{0.26136}{\sqrt{\mathrm{n}^2/\mathrm{A}}} \quad (6)$$

The pattern exhibits clustering if the average nearest neighbor index (ratio) is less than 1. However, if the index is greater than 1, the trend is toward dispersion.

Table5. Average Nearest Neighbor Summary

Observed Mean Distance:	**26.0078 Meters**
Expected Mean Distance:	188.8801 Meters
Nearest Neighbor Ratio:	0.137695
z-score:	-359.279371
p-value:	0.000000

Given the z-score of -359.279371 in table 5, there is a less than 1% probability that this clustered pattern could result froma random distribution. This means that the distribution of the wells subject of this study is clustered and could be considered a good representative for groundwater analysis and prediction in the study area [18].

2.5.2 Regression Analysis

During the analysis phase of this project, a regression equation was used in order to assess the relationship between the collected water levels at the wells and their locations. In our case, the dependent variable to be modeledis the water level, while the independent or explanatory variables are Easting and Northings (Coordinates). Every independent variable is associated with a regression coefficient that describes the relationship's strength between the variable and the dependent one. The regression equation used is described belowwhere Y is the dependent variable (Water Level), the Xs are the explanatory variables (Northings and Eastings), and the βs are regression coefficients:

$$Y = \beta 0 + \beta 1X1 + \beta 2x2 + \beta 3X3 + \ldots\ldots + \beta nXn + \varepsilon \qquad (7)$$

The Residuals are the unexplained portion of the dependent variable (well water level), represented in the regression equation as the random error term ε.

3. RESULTS AND DISCUSSION

This project is a one-year effort targeting registering, collecting, and analyzing data for over 47,000 wells distributed in Dubai Emirate. This project builds a solid foundation to better manage Dubai's groundwater and agriculture resources in the long-term future. Experienced technical teams from the local authoritieshad been allocated to collect this data since January 2018 - resulting in more than six months of technical fieldwork. The field teams recorded each well's location, type, and depth with durable hand-held GPS-equipped devices where the ModeflowMap Mobile solution was installed and configured. They measured groundwater's flow rate, depth, salinity, and hydro-chemical profile at each well site. A registration plate was fixed toidentify each well physically, and the data was uploaded into the ModeflowMap GIS database. Furthermore, the soil samples were collected from four different depths inrandomly selectedlocations, and each was analyzed for soil type and salinity. A portion of these soil samples was also sent to specialized laboratories for further and more detailed analysis.

As a result, processingthecollectedinformation at the level of eachwell combined with administrative historicaldata is considered a key support element to predict and simulate pressures, temperatures, sodium, and other water-related parameters to prevent non-controlled and harmful drilling procedures. Therefore, understanding the spatial distribution patterns of these wells is mandatory [19].

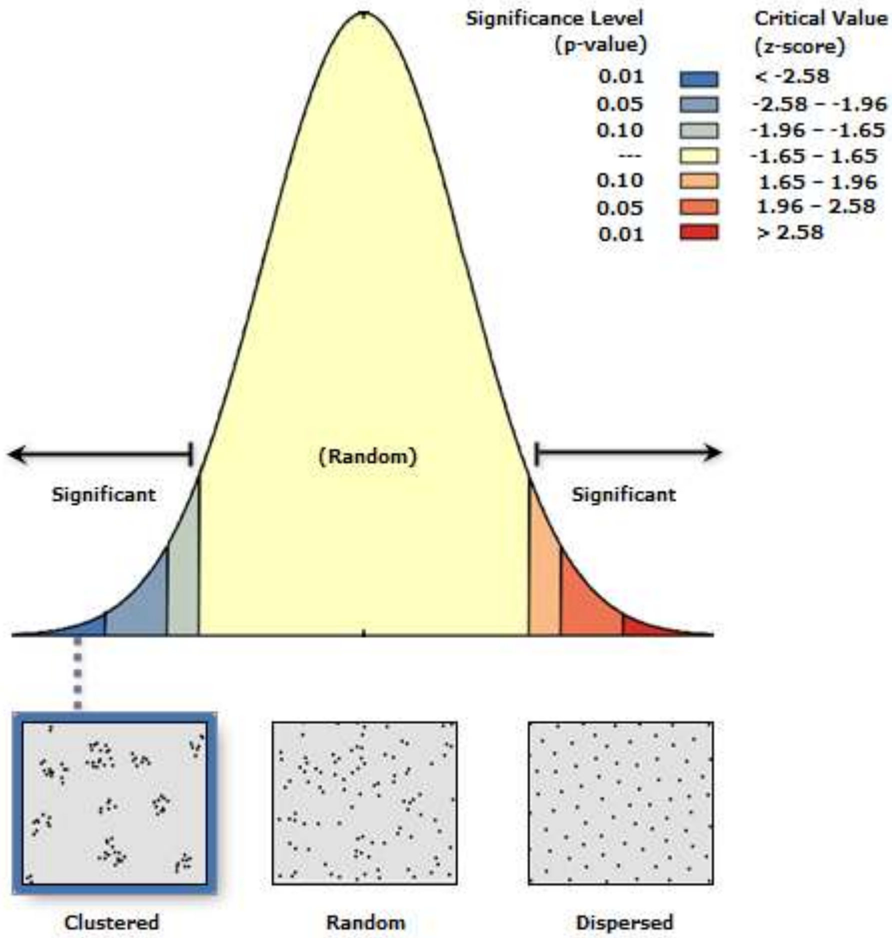
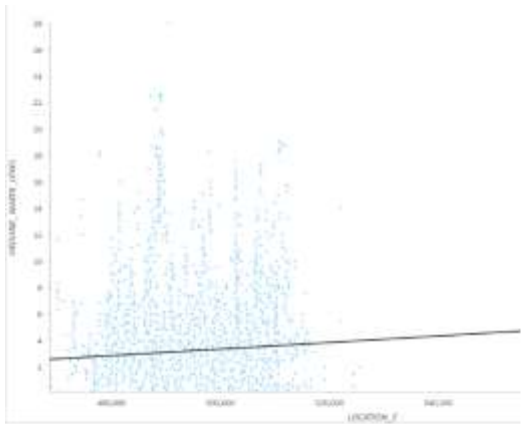


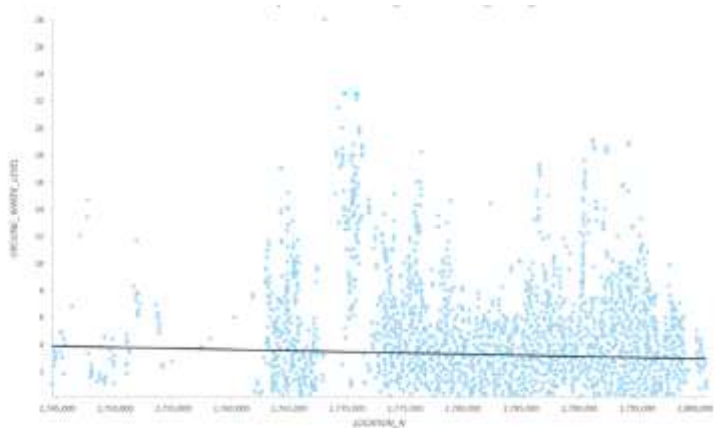
Fig.8. Chart of the Average Nearest Neighbor Summary generated for the Dubai Wells

According to Average Nearest Neighbor summary results, the clustered distribution of the wells in Dubai Emirate suggests that the Dubai wells distribution is clustered and not random, which means that groundwater parameters for a specific well with unknown values can be estimated and predicted based on the nearest wells with known values (z score = -359.279371). Fig. 8 demonstrates the category of Dubai wells distribution as clustered.

The measurements of water levels in groundwater wellsprovide the most fundamental indicator of the status of thisresource. They are critical to meaningful evaluations of the quantity and quality of groundwater and its interaction with surfacewater. Therefore, scatter plotting isused in this study as another way to visualize the relationship between the spatial location and the water level as essential groundwater parameters. As described in the methodology section, a regression equation had been calculated, and the associated trend line and R^2 were plotted on the scatter plots (Fig.9). The trend line models the linear relationship between Latitude, Longitude, and water levels, respectively, and the R^2 quantifies how well the data fits the model.



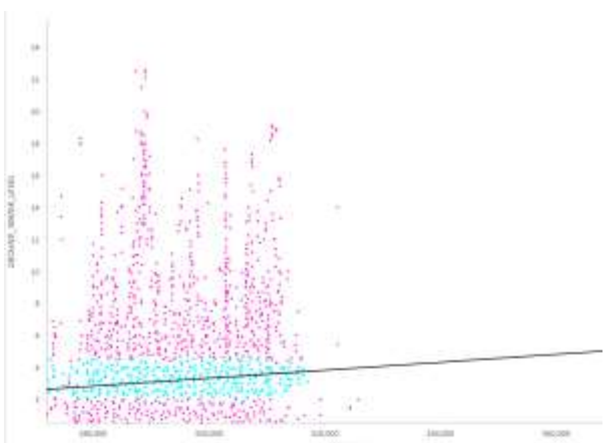
(a)



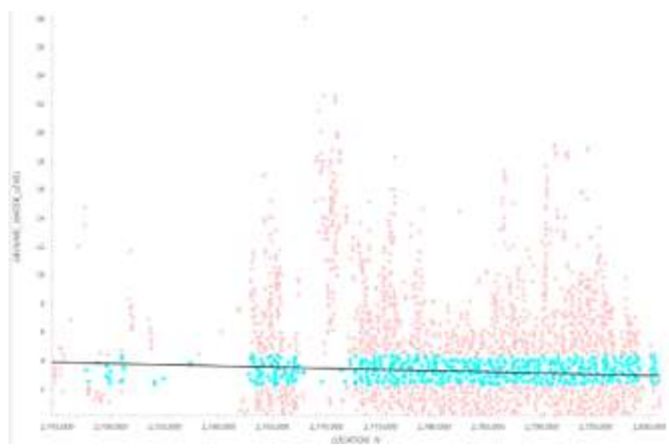
(b)

Fig.9. Scatter plotting of groundwater level vs.(a) Longitude and (b) Latitude

Fig.9 depictsthe relationship between the dependant variable, which is, in this case, the water level against the longitude and latitude as explanatory variables.Overall, for both explanatory variables, R-squared = 0.01, which is 1%, and this means that the model doesn't fit well for prediction if we take into consideration all wells as a frame for sampling; however, more than 50% of the wells fit thisregression model with more than 85%. These wells that fit the regression model are interactively selected through the system and can be used as the main sampling frame (Fig 10).



(a)



(b)

Fig.10. Scatter plotting and selection of best fitting wells to the regression model (85% fit)(a) Longitude and (b) Latitude

Evaluating the residualsis also very important since it can display problematic patterns in the residuals. Fig. 11 portrays these residuals for better regression analysis of the results [20].

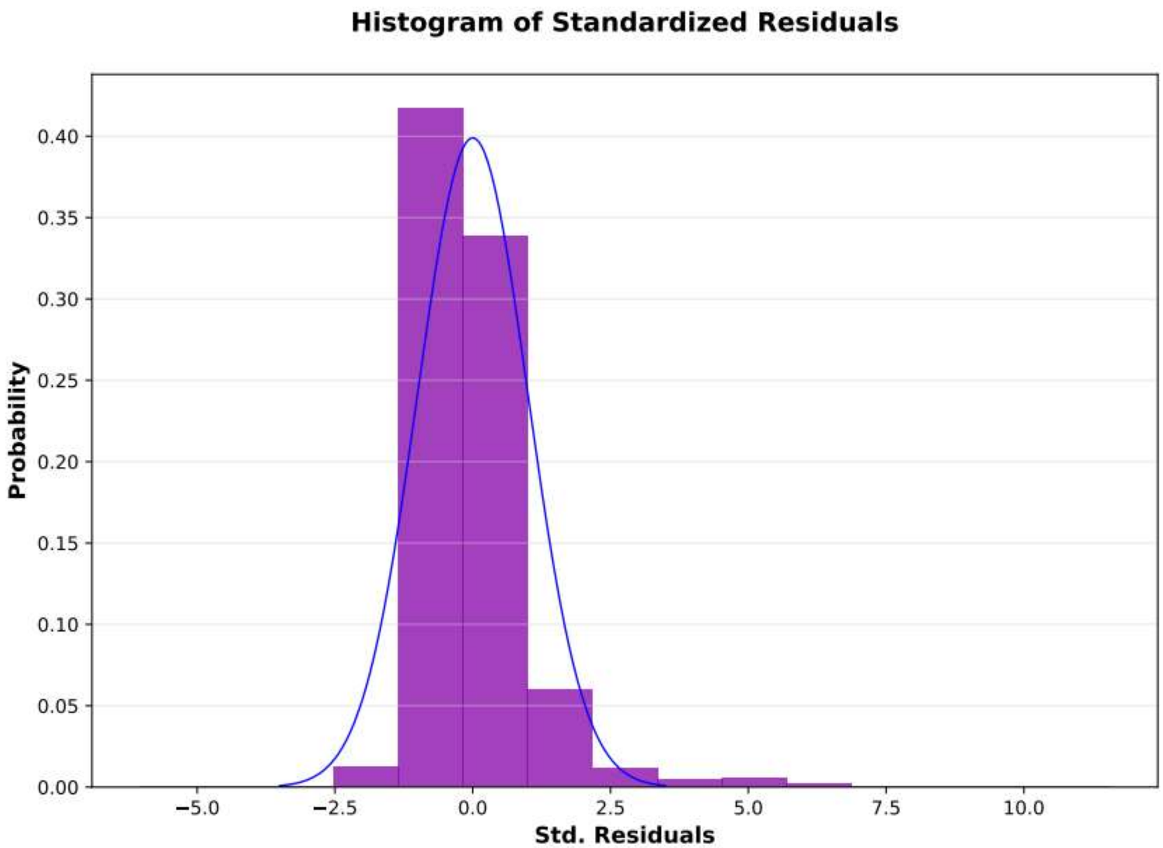


Fig.11. Histogram of standard Residuals for Dubai Groundwater wells Regression model – Water level vs. Spatial location

Overall, this histogram of residuals matchesapproximately the standard curve indicated above in blue.This supports that the regression model is not biased [21].

In order to focus the study and the analysis results on the wells that match the regression model discussed in this paper, a selection of 29,713 wells was made to create the mainframe of wells for groundwater analysis and strategic planning-related tasks. These wells, along with the archived ones, were stored in the central ModeflowMap enterprise GIS database for further analysis, dissemination, and evaluation. Fig. 12 shows an example of filtering the wells based on their type. These wells highlighted in red represent the Dubai Tunnel wells used to monitor the groundwater resources in the proximity of the world's biggest stormwater drainage tunnel.

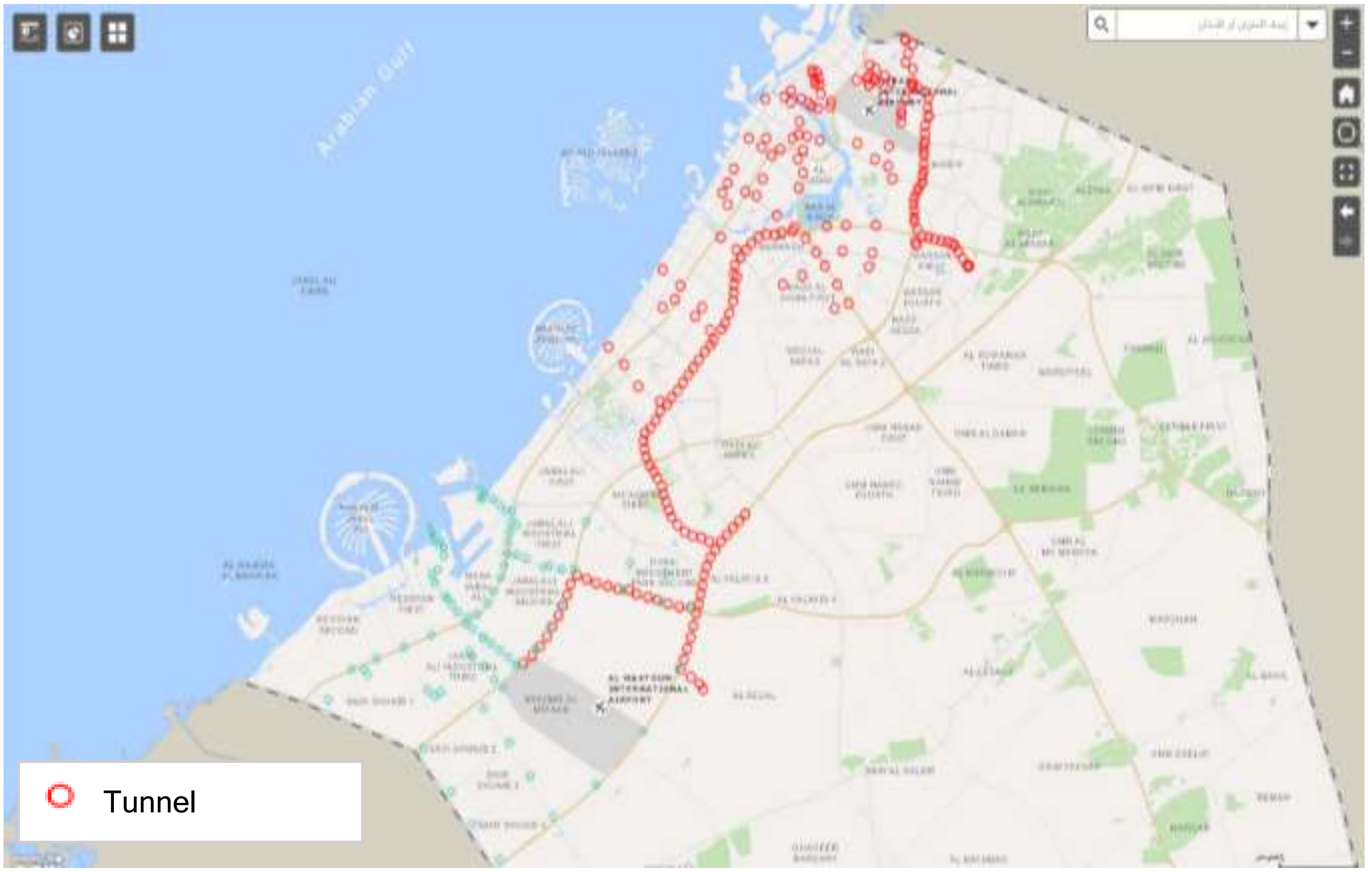
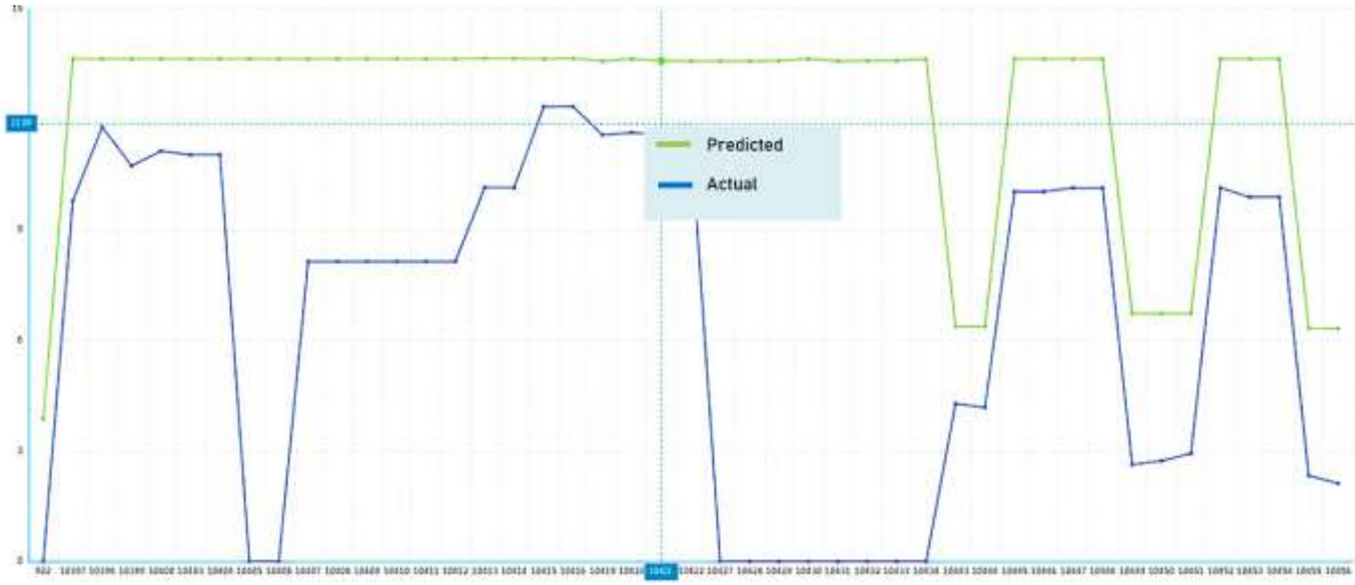


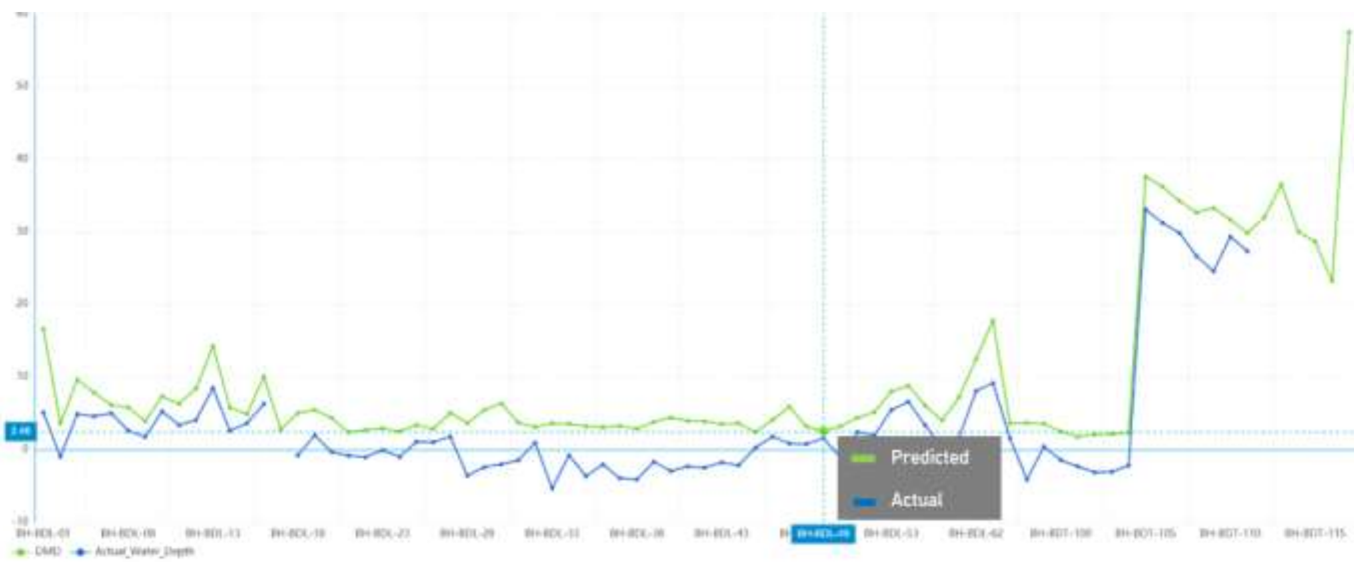
Fig.12. Modeflow Map Web Module- Mapping of Tunnel Boreholes

Fig. 13 displays the differences between the calculated and actual water depths (retrieved from ModeflowMap database) compared to the Dubai Municipality Datum (DMD for some boreholes where the model gives the acceptable results (b) and where it doesn't (a) [22].

In total, 47,433 groundwater wells were registered in Dubai. Of the wells surveyed 43.9 percent were found operational. Most of the wells belonged to agricultural areas, followed by forests and remote well fields. 141 wells were found in regions 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 the surface and large regional.



(a)



(b)

Fig.13. Modeflow Map Web Module- Dissemination of water level prediction vs. Actual

This effort helps establish a baseline for groundwater resources throughout the seasons to identify key performance indicators for agricultural activities' future management plans.

This study also depicts the results of standard spatial analytics used for groundwater, including data elevation modeling, vegetation cover mapping,wells distribution…etc. Fig 14. represents the data elevation model generated from a total of 298,484control points with 100 meters resolution, which was used as the primary reference for calculating the well ground depths versus the Dubai Municipality Datum (DMD), which is also referred to as Dubai Maritime Datum [22].

Fig.14. Data Elevation Model generated from a total of 298,484 control points (100 meters resolution)

Conclusions

The drive of this project has been to illustratethe importance of systematic, long-term collectionof water-level data. Such data are fundamental to understanding and resolving complex water resource issues commonly faced by hydrologists, water-supply managers, engineers, regulatory agencies, and the public.

In order to ensure that adequate waterlevel data are being collected for present and anticipated future uses, observation-well networks need to be evaluated periodically. Therefore, this study depicts the field survey results conducted in Dubai, which covered 47,433 wells and boreholes in the Emirate.

This field survey was conducted using ModeflowMap; an innovative Enterprise GIS Solution developed to collect groundwater quality parameters, including the water level. This tool was the primary solution used to collect groundwater data for 47,433 wells and boreholes in Dubai. It was designed as a preliminary effort to store the records relevant to the quality, quantity, biological, and chemical properties, as well as the type and location of groundwater resources. Such data helped track and analyze the status and uses of groundwater reserves. Furthermore, the findings assisted in improving and promoting the efficient use of water resources in the Emirate.

Such comprehensive effort is mandatory to fully understand the state of the groundwater resources in the Emirate and support the development of effective policies to manage these resources efficiently.

This projectconcluded that geospatial analytics such as Nearest Neighbour and Regression Analysis to model and predict water level data could be used when selecting a frame from the complete set of data to fit the regression model best.

Given the importance of the coordinated efforts between the concerned government departments to collect, analyze and share spatial data related to groundwater resources, the task of deploying ModeflowMap as an integrated solution for collecting critical groundwater wells information to enhance the simulation and the prediction of groundwater is of great value for severalentities. Moreover, the results of this project support groundwater scientists in establishing a clear plan for implementing the necessary framework of policies, data procedures, partnerships, standards, technology, and institutional capabilities that collectively will comprise Dubai's groundwater Resources Hub. +

However, a commitment to long-term monitoring is needed to avoid data gaps resulting from an inadequate distribution of wells or periods of no measurements in a hydrologic record.Disruptions in the hydrologic register can hinder the ability of water-resources managers to make sound decisions. Wherever water-level data are not available, hydrologic information needed to address critical groundwater problems may be impossible to obtain. Although ModeflowMapgroundwater databases can be accessed by many entities, detailed and complete records of historical groundwater data are limited or unavailable. Consequently, potentially valuable data reside in paper files where accessibility and utility are minimal. Finally, to improve the collection and accessibility of water-level data, Dubai Municipality needs to examine ways to enhance interagency coordination in constructing and maintaining observationwells networks, collecting waterlevel measurements, and sharing and disseminating spatial data. Better interagency cooperation will definitely help ensure that data-collection efforts are sufficient to address issues relevant to the greatest variety of the groundwater-resources challenges.

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