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Visualizing the Impacts of Dewatering on Ground Water and Soil Quality Using GIS

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ABSTRACT

There is mounting evidence that the increasing size of the construction industry may lead to significant changes in the global environment. Dewatering, as a crucial component of the construction industry, may have detrimental consequences on the soil and groundwater quality. Dewatering is a technique used to lower the high-water table during construction. The possible effects of dewatering on the soil and ground water quality were visualized and investigated using GIS technology. The analyses were conducted at small temporal and spatial scales. The aim is to give insights in the magnitude and the direction of the dewatering's impacts. Furthermore, the methodology and the results described in this study will contribute to the UAE national analysis of the impacts of dewatering on the water sector. However, field measurements of water table, groundwater qualities, soil salinity levels, geographic locations and elevations were used to verify the spatial analysis conducted. The temporal and spatial variations of the groundwater/soil quality, in the study area, were determined and visualized. Then the impacts of the dewatering were quantified and evaluated. It is found that dewatering has quantifiable impacts on the soil and ground water quality. The results show drastic but reversible changes in water salinity and light but persistent/ irreversible changes in soil salinity. The magnitude of the increase in the water salinity is in the range of 0.4 g/L - 1.8 g/L. While the magnitude of the change in the soil salinity is in the range of 0.02 - 0.04 g/L.

1. INTRODUCTION

Construction has been one of the largest and fastest growing industries in the gulf region where the United Arab Emirates are not exceptional. The construction market in the UAE has been significantly growing. The significant investment in housing and infrastructure development across the country has been energizing the construction industry. The construction market includes a wide range of finished, current, and future construction projects in different sectors. These projects include sub and super structures in residential, commercial, and industrial structures, as well as infrastructure which include roads, airports, power generation and transmission, and recently railways.

It is estimated that 74% of the total area of the UAE is covered by sand dunes which form favorable conditions for a shallow aquifer system [1]. It is very common to encounter underground water at a shallow depth when excavating for a construction foundation. Shallow ground water (high water table), creates unfavorable conditions for construction (unstable excavation and unstable subgrade for foundations) [2, 3, 4]. Therefore, construction in UAE always requires dewatering in order to stabilize the soil and create the favorable (dry) conditions for construction. Dewatering is the process carried out to reduce the high level of groundwater (water table) or removing surface water from a construction site [5]. Dewatering is usually done, by pumping the ground water out of the soil before starting the construction works, to stabilize the soil. Dewatering can be done by various methods; the common dewatering method used in Dubai is the Well-Point dewatering. Dewatering usually continues throughout the construction of the substructures of the project.

Unfortunately, despite the numerous advantages that dewatering offers, it also exerts significant impacts on the environment. One of the main impacts is the deterioration of the soil and the groundwater quality [6]. Sea intrusion is another risk of dewatering especially in the coastal areas like the UAE [6]. When dewatering is practiced in such areas it voids the aquifers and allows for the sea intrusion. Definitely, the sea water that enters the aquifer voids, increases the salts levels in the soil and the groundwater and hence deteriorates the quality of both. The high levels of salts in the soil and groundwater have severe effects on concrete and steel structures as well as the ecology. It is estimated that 68% of the water required for agriculture in the UAE comes from groundwater [7]. This is a huge amount of water affected by dewatering.

While several studies have been carried out to analyze and quantify the impacts of the construction industry on the environment; very few ones have investigated the impacts of dewatering [8, 9, 10, 11]. However, most of these few studies concentrated on the construction related impacts such as soil settlements, landslides, and unstable substructures. While a few studies investigated the impacts of dewatering on groundwater and soil qualities. The importance of groundwater in the UAE as the main resource for agricultural production necessitates studying the impacts of dewatering. Therefore, the possible effects of dewatering on the soil and ground water quality in the Silicon Oasis area in Dubai-UAE have been investigated using GIS technology. The analyses were conducted at small temporal and spatial scales. The aim is to give insights in the magnitude and the direction of the dewatering's impacts. Furthermore, the methodology and the results described in this study will contribute to the UAE national analysis of the impacts of dewatering on the water sector. The specific objectives of the study are to quantify, evaluate, and visualize the temporal and spatial variations of the groundwater and soil quality, in the study area.

2. STUDY AREA

Generally, in developing datasets for such kind of studies (impacts), considerations should be given to issues such as scale of analysis, the availability, accuracy, and adequacy of the data for the analysis and evaluation processes. Such considerations eventually led to the selection of the study area, which best fulfills the above criteria. The area selected for this study is the Silicon Oasis in Dubai, UAE (fig 1). The area is located almost in the center of Dubai with an area estimated to be 7.2 km2. The distance of the study area from the shoreline (sea) is 17.44 km. The ground elevation is as high as 40 m (above SML) at the eastern part of the area and as low as 16 m at the western part (fig 2). The average water table is estimated to be 4.4 m in 2016 [12]. The area consists of a mix of low- and high-rise buildings. The construction in the area has been ongoing since 2005 (fig 3). Due to the high-water table, extensive dewatering has been practiced in the area.

Fig. 1. Study area –Silicon Oasis **-**2008

Fig. 2. Digital elevations of the study area

Fig. 3. Study area –Silicon Oasis – 2011

3. METHODOLOGY

The methodology developed in this study followed the impact approach to assess the dewatering impacts. The impact approach is a straightforward linear analysis of cause and effect [13,14,15,16]. Data sets of soil and groundwater quality are used to estimate the changes that happen in the area as a response to dewatering. Figure 4 shows the steps that are carried out to analyze dewatering impacts. The study used data collected in 2005 as a baseline, and data collected at a later date to analyze and quantify the changes in soil and groundwater quality. The GIS was used to perform the spatial analysis and visualize the results as thematic maps. The following paragraphs describe the methodology in details.

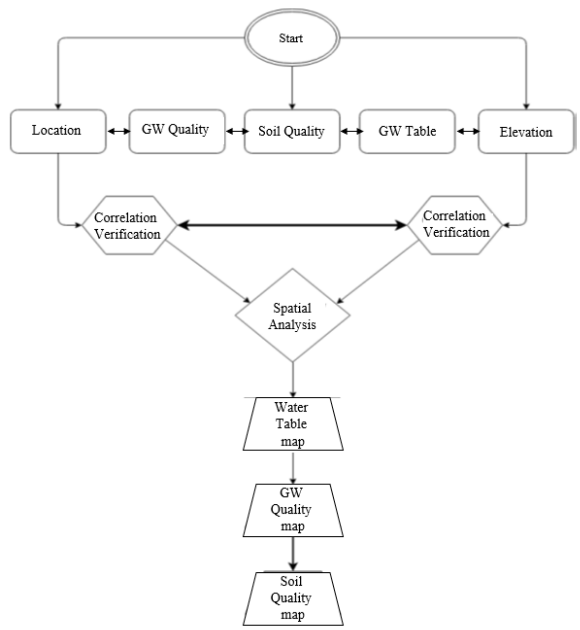

Fig. 4. Flow chart of methodology

3.1. Ground data

In order to analyze and quantify the impacts of dewatering on the study area, soil salinity, water salinity, water pH, soil pH, and water table were extracted from the geotechnical reports as required parameters to perform the analysis (Table 1).

Data Type	Units	Range of values
Water table	m	2.2 - 14
Water salinity	g/L	1.1 – 4.1
Water pH	Moles/L	7.4 – 7.9
Soil salinity	g/L	0.1 – 0.21
Soil pH	Moles/L	7.5 – 8.8

Table 1 Summary of the input parameters

Data processing is an integral part of the GIS workflow, as it involves preparing the data for analysis and visualization. Geographic Information Systems (GIS) involves the collection, storage, analysis, and visualization of geospatial data.

3.2. Image Registering

Satellite image of the study area was extracted from Google earth and imported into the GIS software (Arcmap10) as a base map. The image was then geo-referenced using four ground control points (GCC) shown as yellow points in figure 5. Geo-referencing is the process of relating the digital map coordinates to real-world coordinates.

Fig. 5. Geo-referenced map of the Study area

3.3. Develop shape files for ground data points

The acquired data must be in a format that is compatible with the GIS software, such as shapefiles, geodatabases, or raster formats. Therefore, the datasets were initially stored as geodatabases and then transformed and saved in shapefiles. A shapefile (. shp) is a vector format for storing the geographic location, shape, and attributes of geographic features. The coordinates of the ground data point (locations where the field data were collected) were imported in the GIS and shape was created for each point (fig 6).

Fig. 6. Locations of ground data points

Each shape created is associated with a tabular database file called an attribute table. This table contains information about a set of geographic features, usually arranged so that each row represents a feature (point) and each column represents an attribute related to the feature represented (e.g. x,y coordinates, water table, measured levels of salts).

3.4. GIS Analysis

Sequential GIS processes were carried out to generate a surface that visualizes the spatial variation of each parameter (soil salinity, ground water salinity) over the study area. The shape file of each parameter was used as input to “Spatial analyst” which was opened from “Arctoolbox” as an analysis tool. Then “Interpolation” was chosen as an analysis method to estimate the spatial distribution (values) of each parameter over the area. Kriging was chosen as an efficient interpolation model. Each parameter under analysis (soil salinity, ground water salinity) was chosen as a z-value in krigging model. A surface that shows the spatial variation of each parameter over the area was generated. Then each single surface was clipped by the boundary shape of the study area to make sure that the extent of each single surface is inside the boundary of the study area.

4. RESULTS

The final result of the project shows the impacts of the dewatering process. The following sections depict and discuss the spatial and temporal variation in the water table, water salinity and soil salinity over the years on the study area.

4.1. Water Table

In general, the study area is characterized by low elevation and high-water table necessitating the dewatering. The water table changes have been recorded and documented over the time to monitor the progress of the dewatering.

Figure 7 shows the temporal variation in the water table in the study area. Clearly, the water table started to drop at the beginning of the construction in the year 2005 and continued to drop throughout the construction period. Then, it started to rise again after the construction finished in the year of 2007.

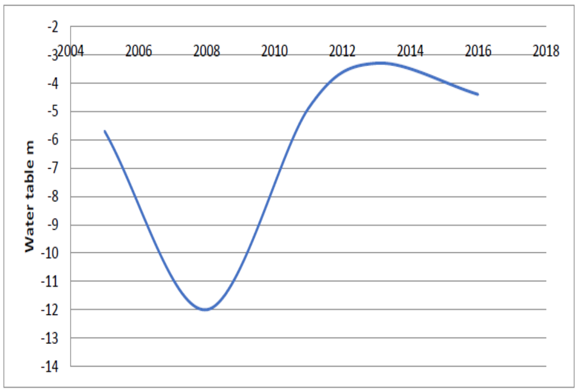

Fig. 7. Variation in water table

4.2. Salinity

This section shows and discusses the variation in the levels of salts in the groundwater and the soil in the study area. Two types of salts were investigated, the sulfate (SO4) and the chlorides (Cl-). To clearly show the impacts, the variation in salts levels after the dewatering is compared to the variation before the dewatering started. The salts levels were measured in grams per liter (g/L). The data of both groundwater and soil before and after construction (dewatering) were taken from soil investigation reports provided by Silicon Oasis authority.

4.2.1. Water Salinity

Figure 8 shows the average levels of the water salinity (sulfate) over the years- temporal variation.

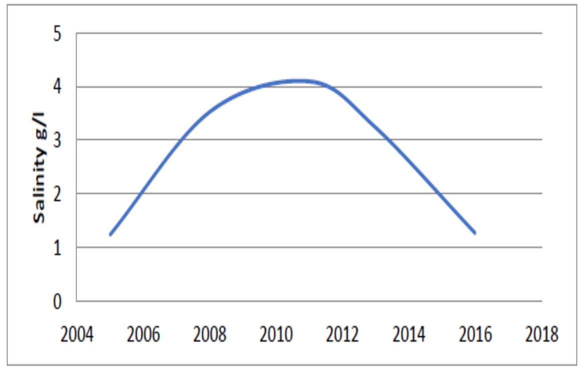

Fig. 8. Temporal variation of groundwater salinity

The figure shows that the level of salts in the ground water started to increase in the year 2005 (the starting of the construction and the dewatering in the area) and gradually increased to reach the maximum in 2011 (the end of the construction and the dewatering in the area) and then gradually dropped after the dewatering activities stopped. Noticeably, it did not drop to the level before the dewatering started. It is clear that the level of salts followed (increase/decrease) the dewatering activities. This drastic increase in water salinity is attributed to sea intrusion. It is well known, if huge amount of water is pumped out from any aquifer system that falls in a short distance from the sea, then sea-water moves landward by a process referred to as "sea-water intrusion." The sea-water enters the aquifer system and infect the soil and groundwater with high amounts of salts and minerals [17]. Due to the relatively short distance between the study area and the sea, all the voids drained from the groundwater are filled by the sea water raising the salinity to high levels.

Figure 9 shows the spatial variation of the water salinity before and after the dewatering activities. The values range from 0.01 g/L (dark blue color) to 4.5 g/L (dark red color).

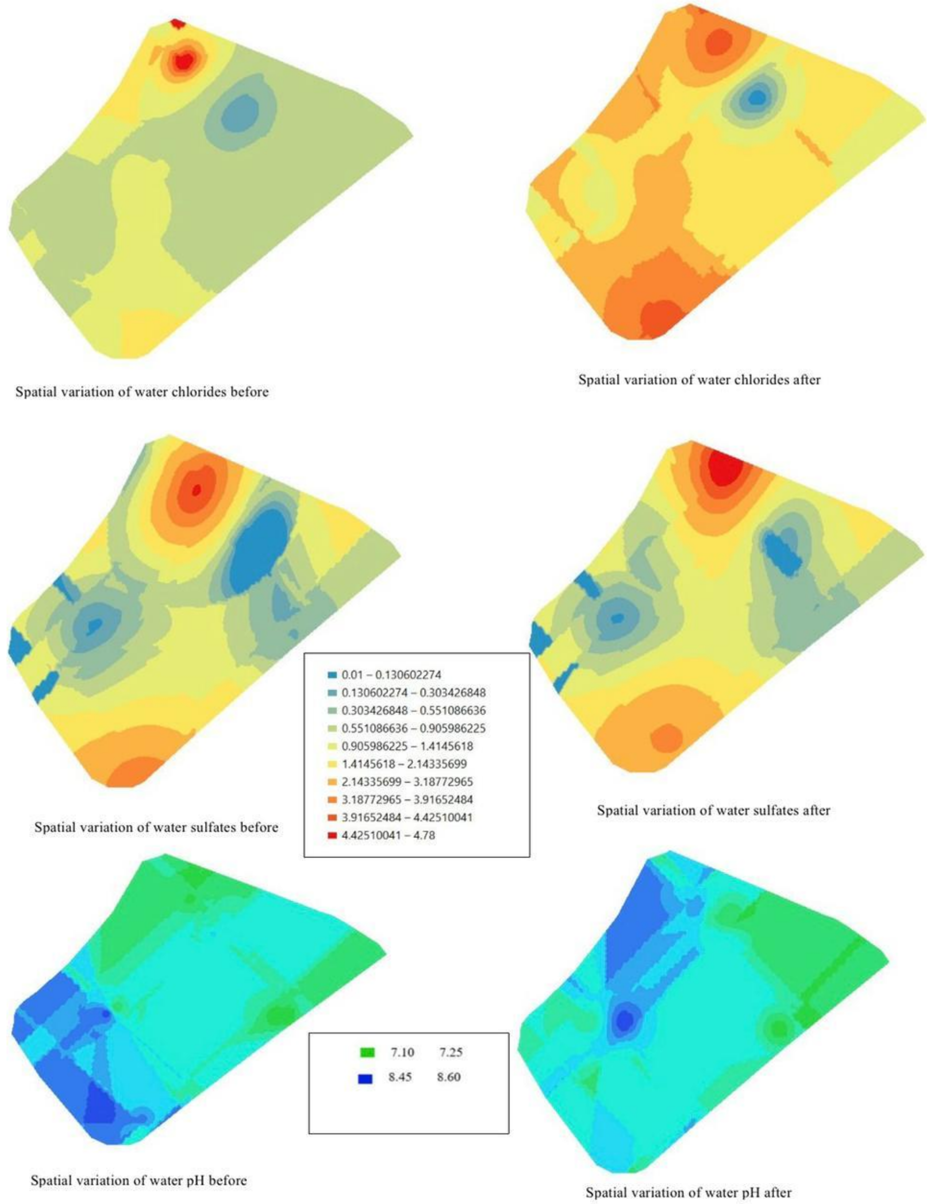

Figure 9. Spatial variation of the water salinity (g/L) before and after

The results show that the salinity is very high at the top and lower corner of the area where the construction (dewatering activity) had been practiced for a while. The figure (fig. 9) shows a vast change in the dominant color in the study area from blue color to yellow/red color. This indicates the huge increase in the salts in the area. Specifically, the area is plagued by the chloride salts. The increase in chloride levels is greater than the sulfate ones because sodium chloride is the most abundant salt in seawater. The magnitude of the increase ranges between 0.4 g/L in some parts of the area to 1.8 g/L in others (average increase of 35%). However, the figure supports the idea that the dewatering had drained the groundwater from the soil voids giving the way to the sea water to fill the voids and hence increase the salinity of the groundwater in the area.

As shown in figure 9 (Spatial variation of water sulfates before/after) there is slight change in the color in the study area. This indicates the small change in the sulfate salts in the area. As mentioned before, the increase in the sulfate levels is less than the chlorides ones. The magnitude of the change is negligible. But, the figure shows that the presence of the sulfates slightly extended to larger area specifically in the upper and lower corners of the area.

Figure 9 also shows the shift in the spatial variation of the salinity in the study area. The high values of the salinity (red color) shifted to the lower corner of the study area following the shift in the construction activities. The shift in salinity levels also supports the insights on the amount and direction of the impacts the dewatering has on the quality of the groundwater. This also reinforces the idea that the main cause of raising the level of salts in groundwater is the sea intrusion.

As shown in figure 9 (Spatial variation of water PH before/after), there is a clear change in the color in the study area especially in the upper corner. The color change from green to blue indicating an increase in the basicity of the groundwater as the result of increase of the salts in the area.

4.2.2. Soil Salinity

Figure 10 shows the average levels of the soil salinity (sulfate) over the years- temporal variation. The increase in sulfate levels is less than the chloride ones because sulfate is the less in seawater. The magnitude of the increase ranges between 0.02 g/L in some parts of the area to 0.04 g/L in others (average increase by 30%).

Despite the data sets being sampled from identical locations for the analysis of soil and water salinity, the figures (Fig. 8 and Fig. 10) reveal stark differences. While water salinity experienced sharp fluctuations, soil salinity exhibited a gradual increase, maintaining consistently high levels. This phenomenon highlights the necessity for special practices to remove the salts from the soil [17].

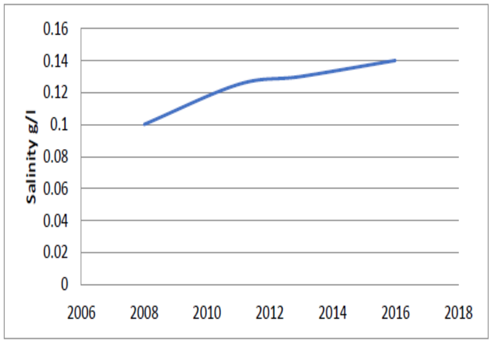

Fig. 10. Temporal variation of soil salinity

However, the results clearly show that the changes in the salts levels at the top and lower corner of the area where the construction (dewatering activity) had been practiced for years. As shown in figure 11 (Spatial variation of soil chlorides before/after) the change in color in the study area is not vast. This indicates that, the change of the chloride salts in the soil is not as vigorous as the one in the groundwater. The increase in chloride levels is greater than the sulfate ones because sodium chloride is the most abundant salt in seawater. The magnitude of the increase ranges between 0.0.89 g/L in some parts of the area to 1.5 g/L in others (average increase by 30%). However, the figure supports the idea that the dewatering had drained the groundwater from the soil voids giving the way to the sea water to fill the voids and hence increase the salinity of the soil in the area.

As shown in figure 11 (Spatial variation of soil sulfates before/after) there is slight change in the color in the study area. This indicates the insignificant change in the sulfate salts in the area. As mentioned before, the increase in the sulfate levels is less than the chlorides ones. The magnitude of the change is in the range 0.02 – 0.04 g/L. However, the figure shows that the presence of the sulfates slightly extended to larger area.

Figure 11 also shows the shift in the spatial variation of the salinity on the study area. The high values of the salinity (red color) shifted to the lower corner of the study area following the shift in the construction activities. The shift in salinity levels also supports the insights on the amount and direction of the impacts the dewatering has on the quality of the soil. This also reinforces the idea that the main cause of raising the level of salts in the soil is the sea intrusion.

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As shown in figure 11 (Spatial variation of soil PH before/after) there is a clear change in the color in the study area especially in the upper corner. The color changes to dark blue indicating an increase in the basicity of the soil as the result of increase of the salts in the area.

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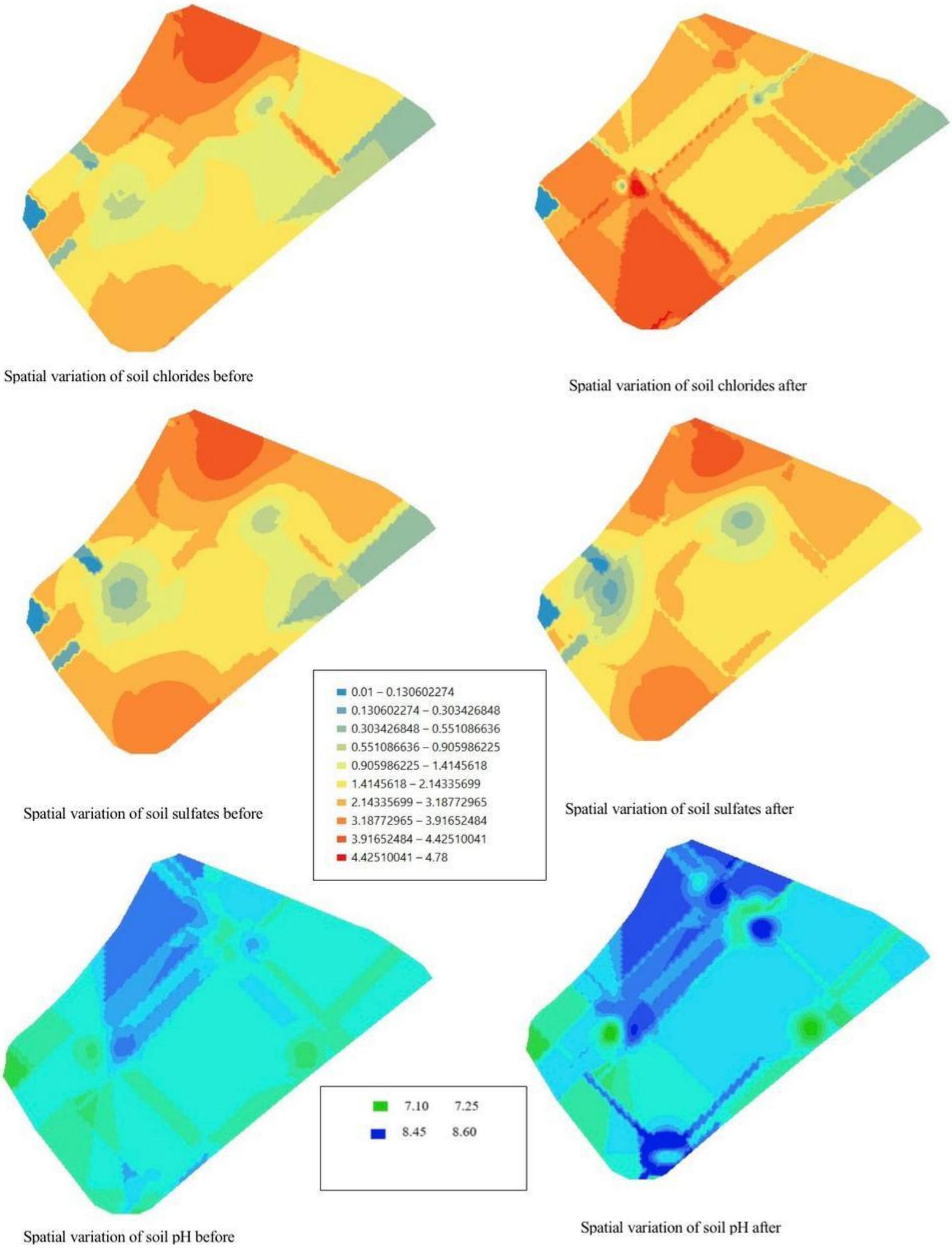

Figure 11. Spatial variation of the soil salinity (g/L) before and after the dewatering activities

5. SUMMARY AND CONCLUSIONS

Dewatering, as a crucial component of construction industry, may have tremendous consequences on the soil and groundwater quality. For safe construction purposes, dewatering is a technique used to lower the high-water table. The possible effects of dewatering on the soil and ground water quality in the Silicon Oasis area in Dubai-UAE were investigated using GIS technology. The aim is to visualize the estimates of the potential impacts of dewatering on the soil and groundwater quality by using smaller temporal and spatial analysis scale and provide results that will be useful for the soil/groundwater planning and management decision-making processes. Field measurements of water table, groundwater qualities, soil salinity levels, geographic locations and elevations are used to verify the spatial analysis conducted. The temporal and spatial variations of the groundwater/soil quality, in the study area, were determined and visualized. Then the impacts of the dewatering were quantified and evaluated. The methodology and results described in this study are contributing to the UAE national analysis of the impacts of dewatering on the water sector. The outcome of this study will help the region plan for changes in the soil and groundwater quality and will give decision-makers a tool for evaluating the impacts of dewatering. The data driven nature of the study makes it flexible so that it can be applied to different areas. The impacts of dewatering were identified by values and rates. All the values and rates were imported into a GIS software. Thematic maps were generated to show the spatial distribution of the impacts on the study area. The main conclusions could be stated as follows:

1. Dewatering has impacts on the soil and ground water quality.
2. The impacts were quantified and visualized using GIS.
3. The results show drastic but reversible changes in water salinity.
4. The results show insignificant but constant changes in soil salinity.

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