The Geographic Information System A Tool for Automatically Illustrating the Microbiological Activities in Groundwater Aquifers (Case study El Bahariya Oasis, Egypt)

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Abstract: The main source of water in Egypt is the Nile, which originates outside the country and is shared by eleven riparian countries. Rainfall is very limited with respect to its geographical and temporal distribution and rates. The other source of fresh water is the groundwater, which represents about 20 % of the available fresh water resources of the country, but is mostly non-renewable. However, if no actions are taken to protect groundwater from degradation, the resource can loose its comparative advantage or even totally lost.
Some Egyptian governorates had observed decline in well yields and deterioration in its groundwater quality. Even after developing these wells no active recovery was reported. Hence, the Research Institute for Groundwater (RIGW, 2004) took over a study to gain a better understanding of the cause of water well problems under the National Water Quality Monitoring Component (Component 1000-NAWQAM). Traditionally water well problems have been attributed to the chemical and physical properties of the well environment. A recent research indicated that water well deterioration is caused by bacteria is called well bio-fouling.
El Bahariya Oasis is a case study of this research. It is located in the Northern East part of the Western Desert of Egypt at about 450 km South West of Cairo and extends northward into the Qattara Depression area. Water samples have been collected from 22 wells to detect the existence and aggressivity of Iron bacteria, Sulphate bacteria and Heterotrophic aerobic bacteria using the biological activity reaction test (BART). The laboratory analysis are conducted in Egypt and supported by the Canadian experts from the Prairie Farm Rehabilitation Administration (PFRA).
The main objectives of this research are to describe Microbiological Testing as a Diagnostic Procedure of Well Yield Reduction and to create and test a GIS program as a tool for automatically illustrating the results of Microbiological Testing (the aggressivity degree of Iron bacteria, Sulphate bacteria, Heterotrophic aerobic bacteria, and Slime Forming bacteria) of the study area water wells.
The results have demonstrated that application of GIS could support demonstrating the relation between the well environment parameters and the BART tests results to with respect to well yield problems. The GIS programming demonstrated that 8 of the sampled wells contain at least one type of high degree of aggressive bacteria, 6 of the sampled wells contain at least one type of medium degree of aggressive bacterial, 12 of the sampled wells contain at least one type of low degree of aggressive bacterial and 5 of the sampled wells indicated no reactions.

1. Introduction

The Geographic Information System (GIS) is being used in a very wide range of applications in several domains such as analyzing satellite images, land survey…etc (Antenucci, et al., 1991). Some functions of the GIS in the field of groundwater management include, among others: (i) storage and retrieval; (ii) constrained query; and (iii) modeling (J. Furst et al.1993; A.Biesheuvel & C.J. Hemker 1993; H.P. Nachtnebel et al. 1993). Taking these functions into consideration, the GIS can be utilized as a support tool in the management of groundwater (De Lange, 1990; Stefen O. Kaden, 1993; K.E. Kolm&J.S. Downey, 1993).

Water wells are the primary water supply source for most remote areas of Egypt, where the Nile River water is not accessible. One of these areas is El Bahariya Oasis which is selected as a case study area to illustrate the role of microbiological activities in the deterioration of water well production. The GIS can play an important role in this respect, if properly used.

Installing and pumping a well increases the level of oxygen and nutrients inside the well and in the surrounding aquifer. This encourages groundwater bacteria to colonize the surfaces in and around the well intake. These colonies will form a sticky gel like substance or biofilm. The biofilm captures

chemicals, minerals and other deposits which move into the well during pumping (Borch et al, 1993; Cullimore, 1993; Cullimore and Legault, 1997; John L. and Twyla L. 2002).

The chemicals and minerals that are concentrated around the well provide food and energy to the bacteria, if left uncontrolled. The biofilms and debris they collect will quickly coat, harden and plug pumps, well screens, water lines, sand pack and even the surrounding aquifer material. In addition the biofilms can increase iron build-up and cause corrosion of the well pumps and in pipe lines (Figure 1).

Figure 1. Effects of Biological Clogging

2. Methods and Procedure
2.1. Approach
To achieve the research objective, the following approach is applied:
- Description of microbiological testing.
- Demonstrating the physical setting of the study area.
- Creating and Testing the application of GIS programming to perform two tasks:
1. Creating the study area location map with production wells.
2. Creating charts of the aggressivity degree for four different types of bacteria (Iron bacteria, Sulphate bacteria, Heterotrophic aerobic bacteria and Slime Forming bacteria) of the study area production wells.

2.2. Diagnostic Procedures
The purpose of the diagnostic field investigations is to determine the cause(s) of well yield reduction which is essential for optimizing the appropriate well treatment process. These field investigations procedures include; a) pumping tests, b) water chemical analysis, and c) microbiological analysis (Maher El Shiwey 2004; Maher El Shewiy et al. 2005). This research focuses on microbiological analysis.

The purpose of the microbiological testing is to determine the degree of the biological activity in the well and in the surrounding aquifer. Well water samples for detecting the bacterial activity were taken before well treatment. The well was pumped for 10 minutes to clean the well water from stagnant water and get aquifer water for sampling. The analyses for bacterial activity are conducted using Biological Activity Reaction Tests (BART^{TM}s), which determine the presence and aggressivity of bacteria that promote biofouling problems. The specific BART^{TM}s used for the microbiological testing of the water were the IRB (for iron related bacteria), the SRB (for sulphate reducing bacteria), the Slym (for slime forming bacteria) and the HAB (for heterotrophic bacteria). All the BART^{TM}s tests results indicated the presence of a highly aggressivity of all detected types of bacteria (DBI, 2002; Sameh Saker et al. 2003).

3. Physical Setting of the Study Area
The Bahariya oasis is located in the Northern East part of the Western Desert of Egypt at about 450 km South West of Cairo. It is one of the seven major oases scattered in the Western Desert of Egypt.

3.1. Climate
El Bahariya oasis lies within the extremely arid belt of Egypt. The climate is warm in winter and hot in summer, with wide diurnal variations and with almost no rainfall. Natural evaporation varies between 5.1 mm/day in December to 14 mm/day during June with an annual average of 9.62 mm/day.

3.2 Hydrogeology
El Bahariya area constitutes a portion of the stable and slightly mobile shelf areas of Egypt. The surface is dominantly occupied by sedimentary rocks. The surface and subsurface geology succession have a thickness of about 3500 meters. These rests unconformably on the basement rocks of Precambrian age. These sedimentary rocks are developed into different facies which are dominated by sandstone and clay in the lower part and by limestone and dolomite in the upper part. El Bahariya area is affected by a variety of fault systems (trending NE-SW, E-W and NW-SW). Fold structures, oriented

mainly NW – SE are detected both on the surface and in the subsurface. The area is also affected by the late tertiary volcanicity and by hydro-thermal activities. The sedimentary succession is developed into the following lithostratigraphic units (arranged from top to bottom):

- Quaternary unconsolidated rocks;
- Lower Miocene sand and gravel;
- Oligocene volcanic;
- Oligocene sand and gravel;
- Upper Eocene gypseous clay and sand;
- Middle Eocene carbonate;
- Paleocene gypseous clay; and
- Upper cretaceous interbedded chalk and clay.

The main aquifer in El Bahariya area is a portion of the regional Nubian Sandstone aquifer system (Mesozoic – Paleozoic) which is very common in northeast Africa. In this aquifer the water exists generally under confined conditions. The groundwater flow direction is from southwest to northeast. Six hydrogeological units are identified:

Unit 1 [Mesozoic – Paleozoic]: is a highly productive and extensive formation. It is composed of porous sandstone and shale. It is locally exposed in the oasis depression and is reported in the subsurface of the whole area. It forms a portion of the regional Nubian Sandstone aquifer system.

Unit 2 [Upper Eocene]: is a low productive and extensive formation composed of sandstone with shale intercalations.

Unit 3 [Moghra and Qatrani Formation]: is a moderately productive extensive aquifer composed of sandstone and gravel with shale intercalations.

Unit 4 [Middle and Lower Eocene]: is a moderately to low productive and extensive formation, composed of limestone and dolomatic with karstified features and fissuring. It occupies a large part of the area, both in the surface and subsurface but is not explored yet.

Unit 5 [Late Cretaceous – Paleocene]: is an extensive and impervious formation dominated by shale beds and acts as an aquiclude between units 2 and 3. It is locally exposed but it is expected in the subsurface in almost all the northern portion.

Unit 6 [Oligocene]: which is composed of hard Pre-Cambrian and volcanic basement rocks; which is extensive and generally low productive unless faulted. This unit is locally exposed in the subsurface of the whole area (unexplored).

Groundwater is discharged by the springs, shallow and deep wells; with a total discharge of about 42 million m3/day.

The Nubian sandstone aquifer system generally is characterized by fresh water (TDS less than 500 PPM). The salinity increases towards the north-east where the salinity rises to more than 1000 ppm.

4. The GIS Programming

To achieve the research objectives, a GIS programming is created to be utilized as a tool for automatically illustrating the results of *BART^{TM}s* Test (the aggressivity degree of Iron bacteria, Sulphate bacteria, Heterotrophic aerobic bacteria and Slime Forming bacteria) of the study area production water wells. The software used for the development of the GIS programming is ArcView 3.1, which has an Avenue language for programming.

During studying the state of the production wells in the study area, it was reported yield reduction, deterioration of the well specific capacity, the change in water color and the high level of iron and manganese, all these factors together indicate that there might be a possible biofouling problems encountered. For interpretation of these observations, water well samples have been collected from 22 wells for the microbiological testing and analysis. The research team developed a criterion to select the sampled wells. Well depth, construction date and discharge nature are the main guide in selecting wells.

The collected water samples have been analyzed for Iron Related Bacteria (IRB), Sulphate Reducing Bacteria (SRB), Heterotrophic Aerobic Bacteria (HAB) and Slime Forming Bacteria (SLYM) by BART^{TM}s to give the aggressivity degree of each type of bacteria using a semi quantitative scale which provides an estimate of the number of bacterial cells present in the water sample. Since each BART test detects a different consortial population, the time lag for one consortium does not directly relate to the time lag for a different test type (DBI, 2002). Since groundwater exploration from wells is done either mechanically using submersible pumps or flowing naturally, water samples should be collected to represent the same hydraulic conditions. The free flowing wells are operating 24 hours/day with no stop and almost the flow rate and the drawdown inside the aquifer and the well are reaching the steady state conditions. For similarity, the pumping wells should be operated long enough under constant discharge conditions until the steady drawdown attained. Under this assumption and protocol, the water samples collected from the pumping wells may not represent the bacterial activities inside the well. The selected water wells are shown in the study area location map (Figure 2) and Table (1) illustrates the results of BART^{TM}s test of the water samples collected from the study area production wells.

4.1 Requirements for Running the GIS Programming Project

The GIS programming contains three Avenue programs (startup, setparameters and chart-b). The

essential elements for creating the GIS programming project are: (i) boundary polygon theme of the study area (Bahariya.shp), and (ii) well point theme in the study area having a dbf-format attribute table containing well data and bacteriological data (Bahwell.shp). These elements a re described in "read me"text file which appears directly from the beginning.

The basic algorithm of the first two programs (startup and setparameters) is depicted in figure (3), while the main programs steps are summarized below:

1. Open the ArcView file ''BartTest.apr''. This step will run the avenue program (startup) that opens "read me" file that describe the purpose and essential elements of the GIS Programming Project.

2. Choose the button [icon] that runs the avenue program (setparameters) to choose the study area boundary polygon theme and well point theme, which facilitate the application of the GIS Programming Project on any chosen area.

3. The main popup menu of the GIS Programming Project will appear (containing the chart button [icon]), charting BART^{TM}s test results.

The output result of the Avenue programs (startup and setparameters) is "read me" file and the main popup menu. This output will show the locations of the production wells in any chosen area, while in this research it will show the locations of the production wells in El Bahariya Oasis, as shown in the view in the popup menu in figure 3. The running time of these two programs is 10 seconds when using a Pentium IV Processor having 1.49 GB RAM.
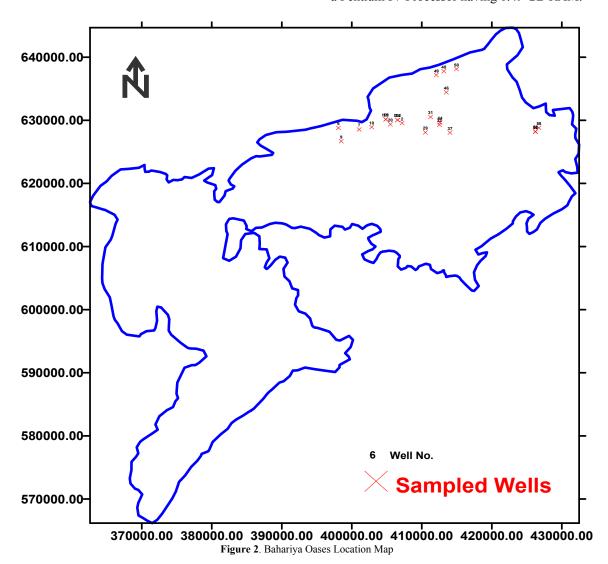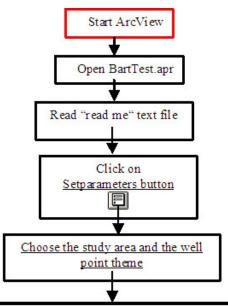

Figure 2. Bahariya Oases Location Map

Table 1. BART^TM^s Test Result

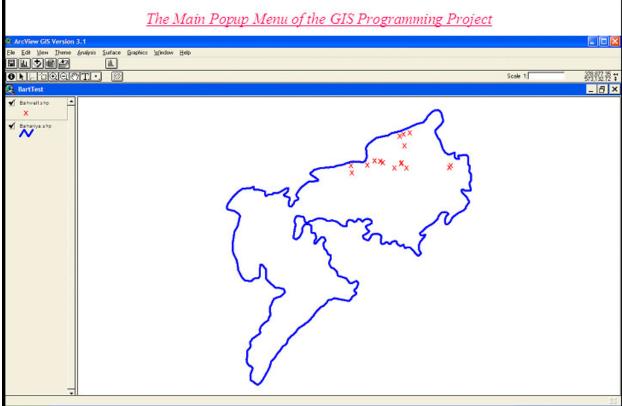| NO.	WELL NAME	AREA	YC	XC	T.D	STATUS	DISCH	C-DATE	SDISC	NOWDISC	OPH	IRB	SRB	HAB	SLYM
6	Barakat	El-Qasr	628793	398091	334	PMP	1568	1995		1773	14	Low	No Reaction	No Reaction	No Reaction
7	El tebnia	El-Qasr	628551	401249	809	PMP	1800	1980	1052	3105	12	Medium	Medium	Low	High Aggressivity
9	Mady	El-Qasr	626691	398489	345	PMP	2640	1992		1821	16	Low	No Reaction	No Reaction	High Aggressivity
10	Ain embash	El-Qasr	628923	402836	250	PMP	1254	1976		1331	11	No Reaction	No Reaction	High Aggressivity	High Aggressivity
15	Ain Elser	El-Qasr	630150	404848	106	Flow	960		2443	2443		No Reaction	No Reaction	No Reaction	No Reaction
ID1	Private	El-Qasr	630150	404848	150	Flow		2001			24	Low	No Reaction	Medium	High Aggressivity
20	El qlise	El - Ba	629367	405542	768	PMP	1344	1983	1399	1165	14	No Reaction	No Reaction	No Reaction	No Reaction
24	dehkma	El - Ba	630058	406536	811	Flow	1280	1984	4290	1144	16	No Reaction	No Reaction	No Reaction	High Aggressivity
27	halfa	El - Ba	629554	407181	111	PMP	1755	1994	750	2258	13	No Reaction	No Reaction	No Reaction	Low
ID2	Private	El - Ba	630058	406536	120	Flo		1998			24	Medium	Medium	High Aggressivity	High Aggressivity
29	elaguz east	El-aguz	628079	410507	104	PMP	1557	1994	182	2144	9	No Reaction	No Reaction	No Reaction	No Reaction
31	el ghaba el	Mandish	630531	411258	291	PMP	1824	1990	642	2045	16	No Reaction	Low	No Reaction	Low
32	el kber	Mandish	629277	412517	746	PMP	1395	1966	3240	1296	15	No Reaction	No Reaction	Medium	Low
37	segam	Mandish	628050	414023	781	PMP	1988	1992		2692	14	Medium	Low	No Reaction	Low
44	el habase	El-Zabu	629645	412605	498	PMP	1778	1981	750	1138	14	Low	Low	No Reaction	No Reaction
46	Eldolab El-	El-Zabu	634435	413505	106	Flow		2001	3600		24	No Reaction	No Reaction	No Reaction	Low
48	Qasa 2	El-Qasa	637768	413153	654	Flow	600	1967	9330	1054		No Reaction	No Reaction	No Reaction	No Reaction
50	qasa 3 r	El-Qasa	638107	414956	954	Flow	3048	1998		4800		No Reaction	No Reaction	No Reaction	Low
49	qasa 1	El-Qasa	637170	412081	781	Flow	1032	1990		1549		No Reaction	No Reaction	No Reaction	Low
55	ain gded	El-Hara	628218	426235	816	PMP	1100	1980	2800	1830	10	No Reaction	No Reaction	No Reaction	No Reaction
56	ain gded 2	El-Hara	628187	426234	974	PMP	900	2000			10	Medium	No Reaction	High Aggressivity	High Aggressivity
58	ain el bahr	El- Har	628826	426735	206	PMP	1106	1986		670	14	No Reaction	No Reaction	No Reaction	High Aggressivity

Figure 3. Algorithm of startup and setparameters Programs

4. 2 Presenting the BART[TM]s Test Results

The third Avenue program in the GIS Programming Project, that gives the chart of the aggressivity degree of the chosen bacteria (Iron bacteria, Sulphate bacteria, Heterotrophic aerobic bacteria and Slime Forming bacteria) in El Bahariya study area, it is called chart-b and is running when the user click on the chart button ▦ that created in the popup menu.

The main characteristics of the program, including its input data, program algorithm, as well as the output results, and running time are summarized below:

Input data: The program (chart-b) poses a query about the bacteriological elements of interest. These input data are specified, chosen and taken from the well theme dbf attribute table as discussed before.

Program algorithm steps: The algorithm of program (chart-b) is depicted in figure 4, while the main program steps are summarized below:

- ❖ Message box for element selection;
- ❖ Get the dbf table of well theme;
- ❖ Clear any selected set on the table;
- ❖ Create a chart that contains the aggressivity degree of the chosen bacteriological element for El Bahariya water samples;
- ❖ Set the name for the chart (The Distribution of "chosen element"); and
- ❖ Display the chart.

The output of program (chart-b) is a chart that shows the aggressivity degree of a certain chosen bacteriological element. The results indicate that 8 of sampled wells contain at least one type of high degree of bacterial aggressivity, 6 of sampled wells contain at least one type of medium degree of bacterial aggressivity, 12 of sampled wells contain at least one type of low degree of bacterial aggressivity and 5 of sampled wells indicated no reactions. The aggressivity degree of the four types of bacteria which resulted from chart-b program is summarized as follows:

1) **IRB Aggressivity:** BART[TM]s test results indicated that 4 of the samples contain medium aggressivity degree of IRB, 4 of the samples contain low aggressivity degree of IRB and 14 of the samples have no reaction. No samples were recorded as high aggressivity degree (Figure 5).

2) **SRB Aggressivity:** 17 samples out of 22 have no reaction, while 2 well samples were observed as medium aggressivity degree of SRB and 3 well samples contain low aggressivity degree of SRB. No samples were recorded as high aggressivity degree (Figure 6).

3) **HAB Aggressivity:** High aggressivity degree of HAB have been observed in 3 well samples, while 2 samples indicated medium aggressivity degree and only one sample contains low aggressivity degree of HAB. No reaction was observed for 16 well samples (Figure 7).

4) **SLYM Aggressivity:** BART[TM]s test results indicated that 8 of the samples contain high aggressivity degree of SLYM, 7 of the samples contain low aggressivity degree of SLYM and 7 of the samples have no reaction. No samples were recorded as medium aggressivity degree (Figure 8).
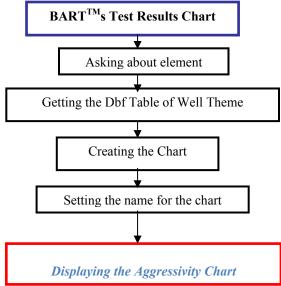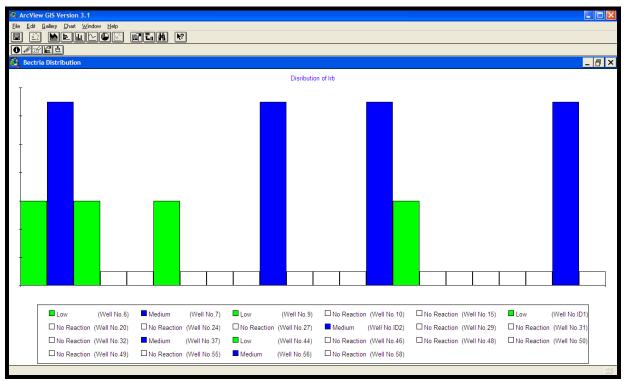

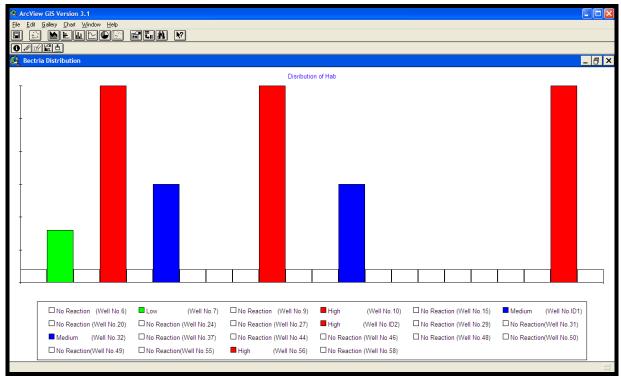**Figure 4.** Algorithm of (chart-b) Program

Figure 5. IRB Aggressivity Level

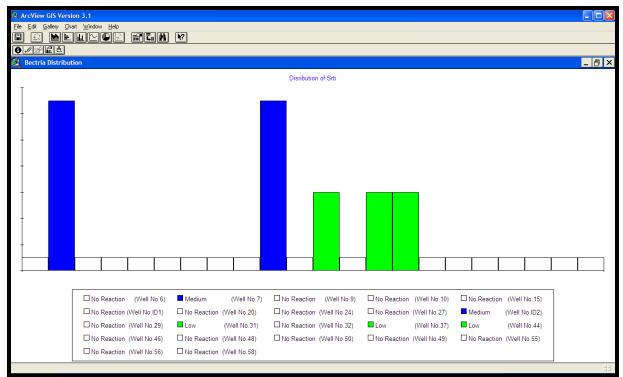
Figure 6. SRB Aggressivity Level

Figure 7. HAB Aggressivity Level

Figure 8. SLYM Aggressivity Level

When using a Pentium IV Processor having 1.49 GB RAM, the running time will be about 3 seconds for each chosen bacteriological element.

5. Conclusions and Recommendations

Based on the results of our practical investigations contained here, concerning creating and testing the GIS programming for presenting the results of microbiological tests of water samples collected from the study area production wells, the following conclusions and recommendations can be enumerated:

- The created GIS programming is a user-friendly system.
- The GIS programming can support decisions on the relations between the well environment parameters (well depth, construction date and discharge nature) and the BART tests results to detect the reasons of the well yield problems as a step to solve such problems.
- Results of the application of the GIS programming indicated that:
    1. 8 of sampled wells contain at least one type of high degree of bacterial aggressivity;
    2. 6 of sampled wells contain at least one type of medium degree of bacterial aggressivity;
    3. 12 of sampled wells have low degree of bacterial aggressivity; and
    4. 5 of sampled wells indicated no reactions.

It is thus recommended to develop modules are capable to support the design of well environment protection zones.

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