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Management Scenarios of Moghra Aquifer, Western Desert, Egypt

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ملخص البحث

تعتبر المياة الجوفيه أحد أهم البدائل الهامة عن نقص المياة السطحية و خاصة فى بلد تعتبر شبه قاحلة مثل مصر ذات زيادة سكانية سريعة لذا فان الخزانات الجوفيه تعتبر من الثروات الطبيعية , و خزان المغره المتواجد بمنطقة الصحراء الغربية يعتبر ذو امكانات عالية من حيث كميات المياة و لكنه فى ذات الوقت تعتبر مياهه شبة مالحة حيث أن كمية الاملاح الذائبة تتراوح بين 3000 جزء فى المليون الى 10000 جزء فى المليون لذا تقلل من الخيارات المطروحة أمام استخدام المياه . خزان المغرة يقع على مساحة حوالى 73.300 كم^2 والخزان يعتبر من الخزانات الواعده و سوف يتم الاعتماد عليه لاستصلاح 170 الف فدان كجزء من خطة الدولة الاستراتيجية فى استصلاح حوالى 1.5 مليون فدان , لذا كان من الاهمية بمكان حساب سيناريوهات التشغيل بعد معايرة النموذج الرياضى باستخدام برنامج Visual Modflowوحساب خرائط مناسيب المياة(Groundwater levels Maps) بعد تشغيل الآبار التى تم حفرها بالمنطقة وكذلك حساب الهبوط الناتج عنها وان كان سيؤثر فى استمرارية الخزان الجوفي, تم حساب اربع سيناريوهات لتشغيل الابار علي كميات سحب مختلفة . السيناريو الاول يتضمن تشغيل الآبار بكامل طاقتها الانتاجية 100% والسيناريو الثاني يتضمن تقليل كميات السحب بنسبة تصل الى 50 % والثالث تقليل كميات السحب الى نسبه 70 % و الرابع تقسيم منطقة الآبار الى ثلاث مناطق مع الاحتفاظ بمعدلات السحب لاول منطقتين وتقليل معدلاتها فى المجموعة الثالثة بنسبة 70 % و قد وجد ان السيناريو الثالث و الرابع افضل لعدم وجود مناطق جافة و السيناريو الثالث افضل من حيث الهبوط الناتج داخل الخزان الجوفي.

1- ABSTRACT

The groundwater is one of the most important alternatives due to the lack of surface water, especially in a semi-arid country such as Egypt with a rapid population increasing. Moghra aquifer is one of the groundwater aquifers resources; which is located in the western desert; has high potentiality in terms of quantities of water. At the same time, its water is considered brackish, as the amount of soluble salts ranges from 3000 ppm to 10,000 ppm, thus reducing the options for utilization. The aquifer covers an area of about 73 km^2 and it is considered one of the promising aquifers in Egypt. It is planned to reclaim 170 thousand fadden as part of the state strategic plan to reclaim about 1.5 million feddan utilizing this aquifer. , This work aiming at evaluating operating scenarios following calibrating the model using the Visual Modflow. Four scenarios were conducted on different pumping rates. The first scenario involves the operation of wells at full capacity of 100%. The second scenario involves reducing discharge rates 50%. The third, reducing the rates by 70%. Fourth, allocating the wells into three groups, and then retaining the pumping rates for the first two groups and reduce the rates in the third group by 70%. It can be concluded that the third and fourth scenarios were found to be better because there were no dry areas and the third scenario was the best in terms of the declination in the groundwater levels.

It is recommended that when data are available sequentially that the aquifer is reassessed under un-steady conditions and thus scenarios are developed based on the updated data, also monitoring system will be necessary for accurate future assessment.

Keywords: Visual Modflow, Moghra aquifer, groundwater levels

1- <u>Introduction</u>

Groundwater Aquifers is considered an important natural system to keep water naturally, the groundwater aquifers can be distinguished according to many features like the geological age, if it renewable or not, the types of water bearing layers, the water quality and etc.(Bear J., 2009). Moghra aquifer is located in the western desert at the north portion, as shown in Figure (1). The aquifer surrounds by an especial geomorphology units like Wadi-El Natun in the east and Qattara Depression in the west, also the Moghra oasis is considered especial part (Grolier, McCauley, Breed, & Embabi, 1980), the aquifer area is about 73.000 km^2 and the water table elevations are varying from -60 m at the south west of the aquifer to about 0 m at the north and north east and groundwater direction is from east to west.

There are many tools to evaluate the potentiality and quality of the aquifers. Numerical models is one of the important tools and is a very effective one (Baalousha, 2009), these models is based on finite difference, finite element or finite volume. ModFlow is a developed program based on the finite difference method, it can solve the groundwater flow equation and fate and transport equation with high accuracy(Igboekwe & Amos-Uhegbu, 2011). ModFlow will be the evaluation tool for the study area (Moghra aquifer).

2- <u>Background</u>

The groundwater research is a focus of attention for more than 80 years because of the importance of finding alternatives to surface water and maintaining them, also excessive water withdrawal is considered a serious problem and threat the presence of these aquifers, many researches carried out their studies by various methods, one of the most popular one is by using models. ModFlow is considered one of the most famous of these models because of its good simulation of the physical system.
because of the old fashion belief of the using the Mediterranean Sea water to generate electricity in Qattara Depression many researches were carried out to evaluate the Moghra quantity and quality as well as the petroleum researches in the same area, the following paragraph present some of them.

Rizk. Z. S and Davis. A. D (April 1991): Two-dimensional finite difference model was constructed to evaluate the rise of water table of Moghra aquifer, and calculate the effects on the quality due to the Mediterranean Sea saline water. Geological, meteorological, stable O^{18} data were used to define the model boundary. The conceptual model assumptions which were used to evaluate the effects were:

1- The water table fluctuation of the Moghra aquifer was neglected,

2- Five resources of recharging the aquifer are a) precipitation, b) groundwater seepage from Marmarica layer, c) the recharge due to the River Nile in the east portion, d) salt water intrusion from the Sea, e) the upward leakage from Nubian Sandstone in the southwest direction,

3- Evapotranspiration of the Qattara Depression was pointed in six areas.

The results of the research predicted that the rise of the Moghra aquifer's water table would be about a 30-m in the central part of Qattara Depression. This water-table rise declines sharply to the north and east. The quality of Moghra aquifer would be turn to be hyper saline.

Sefelnasr. A. M (November 2007): The researcher developed a three-dimensional transient groundwater flow model for the Nubian Sandstone Aquifer System (NSAS) that is based on GIS-Database integration. The study took into consideration the regional boundaries of the Nubian Sandstone aquifer and recognized the most effected sources/sinks features. Local model also was developed without consideration of the regional boundary conditions in Dakhla oasis, Lake Nasser, and the Tushka area, the results of five extraction scenarios showed the declining of the water table from 5 m in the Bahariya oasis to 36 m (bgl) in the Kharga oasis at the end of the simulation at the chosen year (2100). The results of these scenarios made a different effects on the chosen investigated areas(Sefelnasr 2007).

Mohamed, R. F, Hua, C. Z, (February 2010): A three-dimentional flow model was developed by Modflow code for the Western Nile Delta to define the reduction percentage of extraction rates to achieve more stability in the aquifer. Calibrated model was applied to check the input parameter (hydrulic conductivity and recharge boundary), also all canals and main drains were inserted as river in the model, the search defined the percentage by 20% abstraction less for more sustinability of the western Nile Delta aquifer(R.F. & C.Z., 2010).

Abbass, S.Z, (2017): A three-Dimensional conceptual groundwater model was developed in north portion of the Western Desert. The conceptual model was constructed and calibrated to evaluate three scenarios for groundwater withdrawal and their corresponding effects on the groundwater potentials during 50 years in Wadi el-Farigh area, from the results of simulations, it was advised that the groundwater extracting rates should not exceed the calculated safe yield which is approximately equal to 300000m3/day(Abbass, 2017).

3-Geology Study

The study area follows Miocene sediments, and they are well exposed along the escarpment bordering the Qattara Depression, they extend from Wadi El Fareigh in the east to longitude 27º30′ westward. Eastwards they disappear under Pleistocene to Holocene clastic deposits (Ezzat M.A., 1984). They disappear towards the east beneath the clay and silt of the Nile Delta (El Abd E.A., 2005)

The thickness of the Miocene sediments varies between 800 to 1000 m (Ezzat M.A., 1984), according to El Shazly (1975, 1976), the Miocene sediments consists of two formation (Gebel EL- Khashab formation and Qaret El-Hadid formation). The Moghra formation which was named by Said (1962) to represent the Lower Miocene sediments in the area between Moghra and Siwa Oasis.

The Lower Miocene clastic Sediments: Moghra Formation extends from north of Wadi EL Fareigh in the east to Qattara Depression in the west, down to the uplifted area Bahariya-Abu Roash. This formation forms the bottom and the surroundings of the north –eastern part of Qattara Depression.

Between the Qattara Depression and the Mediterranean Sea, EL-Diffa Plateau is exist which is covered by Middle Miocene Jaghbub formation (Marmarica Formation). It is a sequence of calcareous sediments of a thickness of a few meters at the depression rim and increasing to several hundred meters at the coast where Pleistocene carbonate rocks (Alexandria Formation) cover the older formation.

4-Hydrology

4-1 Climate Condition and Rainfall

The Western Desert is considered an arid region except the shore line of the Mediterranean Sea, the average meteorological data is collected in period from 1971 to 2000 from two stations Alexandria in the west and Matrouh in the East, (ministry of agriculture and land reclamation, 2007). The Mediterranean coastal zone of Egypt receives noticeable amounts of rainfall, especially in winter. The annual rainfall is low as it does not exceed 16. 6 mm. The maximum monthly rainfall is 55.6 mm in December in Alexandria while the maximum monthly rainfall is 33.2 mm in January in Matrouh from 120 mm. In the southern direction annual rainfall decreases sharply to 55 mm at Wadi El-Natrun to 20 mm at Qattara Depression (WRRI 2018).

In the southern area of Qattara Depression annual rainfall decreases to 10 mm, the maximum temperature in the western desert ranges between 19.7 and 38 C and minimum temperature between 4.1 and 20.7 C.

The amount of rainfall in the study area is not a considerable enough to be included in the assessment.

4-2 Recharge Sources of the Moghra Formation

The recharge of Moghra Aquifer coming from many sources:

1- The Mediterranean salt water which have hydraulic connection with the northern part of the aquifer, and it will be considerable in model input,

2-Rechage from the deep Nubian Sandstone aquifer, and it will be considerable in the southwest portion in the model area,

3- The Nile Delta aquifer from the north-west direction (RIGW, 1990).

5-Hydrogeology

5-1 Aquifer Geometry

The aquifer follows the Lower Miocene sands and sandstone and it outcropping also in the area south Wadi El-Fareigh to Berkit Qarun, the flow of groundwater is from east to west which indicates that Qattara Depression acts like a natural drain, the aquifer consists of two layers, Marmarica layer and Moghra layer, the two layers are hydraulically connected, the recharge of Marmarica layer recharge coming from the western fringes of the Nile Delta Basin and by small amount of local rainfall while the Moghra layer recharge coming from the Nubian Sandstone Aquifer.

5-2 Piezometric Head of the aquifer and depth to ground level

The collected data from maps of the study area shows that the groundwater levels vary from 0 m to -70 m below mean sea level, the maps are used instead of the specified wells because of the non-availability of the observation wells, two sources show the head map and the direction of the groundwater flow, the hydrological map of Egypt (RIGW 1988), (Figure 3) and the other one from Qattara Hydro Energy project side effects on Groundwater Aquifers (Ezzat M.A., 1984), (Figure 4).

6-Numerical model

The most popular two methods to solve a set of differential equations are finite difference and finite element. The two methods depend on discreet the problem domain either in rectangular shape or squared shape or triangular shape. Finite Difference is the chosen method for solving the current problem and achieve the objectives of the paper.

6-1 MODFLOW

MODFLOW is the USGS's three dimensional (3D) finite-difference groundwater model, it solves the fundamental equation of groundwater flow(Woessner & Anderson, 1992) (equation 1) by using the finite difference method. A build-in mesh allows model to define each cell property, each cell is connected with the others by equations and can easily defined as source/sink point and has its own characteristics.

$$\begin{aligned} & CR_{i,j-1/2,k}\left(h^{m}_{i,j-1,k} - h^{m}_{i,j,k}\right) + CR_{i,j+1/2,k}\left(h^{m}_{i,j+1,k} - h^{m}_{i,j,k}\right) \\ & + CC_{i-1/2,j,k}\left(h^{m}_{i-1,j,k} - h^{m}_{i,j,k}\right) + CC_{i+1/2,j,k}\left(h^{m}_{i+1,j,k} - h^{m}_{i,j,k}\right) \\ & + CV_{i,j,k-1/2}\left(h^{m}_{i,j,k-1} - h^{m}_{i,j,k}\right) + CV_{i,j,k+1/2}\left(h^{m}_{i,j,k+1} - h^{m}_{i,j,k}\right) \\ & + P_{i,j,k}\, h^{m}_{i,j,k} + Q_{i,j,k} = SS_{i,j,k}\left(\Delta r_j \Delta c_i \Delta v_k\right)\frac{h^{m}_{i,j,k} - h^{m-1}_{i,j,k}}{t^{m} - t^{m-1}} \end{aligned} \tag{1}$$

Where hmi,j,k is head at cell i,j,k at time step m (L); CV, CR, and CC are hydraulic conductance, or branch conductance's, between node i,j,k and a neighboring node (L2/T); Pi,j,k is the sum of coefficients of head from source and sink terms (L2/T);
Qi,j,k is the sum of constants from source and sink terms, with Qi,j,k< 0.0 for flow out of the ground-water system, and Qi,j,k> 0.0 for flow in (L3/T); SSi,j,k is the specific storage (L-1); Δrj is the cell width of column j in all rows (L); Δci is the cell width of row i in all columns (L); Δvk is the vertical thickness of cell i,j,k (L) and tm is the time at time step m (T).

6-2 Construction of the conceptual model

The conceptual model is descriptive representation of groundwater system incorporating of geological & hydrological conditions. The area which is modeled is about 73.300 km^2, the model domain is divided into 75 rows and 100 columns with area of 5000 m length and 5000 m width for each cell.
The model cells categorized to active and inactive, one layer with variable width ranging from (400 m above mean sea level to -900m) is presented based on the boreholes data, and known hydrogeological boundaries are inserted in the model.

6-3 Aquifer Characteristics

The entire parameters of the aquifer (aquifer characteristics) like Hydraulic conductivity (K) and Strotavity(S) are the most sensitive parameters in model construction. The parameters are collected from the previous studies in addition to the pumping tests which were carried out on some drilled wells. They can define the amounts of water which crossing into or out of the aquifer, the Transmissivity (T) in the Moghra Depression varies from (419 to 3600) m^2/day, and hydraulic conductivity (K) ranges from (0.83 to 14.28) m/day also Strotavity S ranges from 9.15x 10^{-4} to 0.25.

6-4 Boundary conditions

Hydrogeological Boundaries are defined based on the classification of boundary conditions concepts and equations (Dirlichit, Neuman, and combination between them) as illustrated below(Brikowski, 2010):

1- The Mediterranean Sea is bounded the domain in the north sector, the length of the shore line is about 536 km, although there is a low permeable facies of clay separated the coastal aquifer and Moghra aquifer, The Mediterranean Sea is described as a constant head boundary with start time head and stop time head = 0 m and the separated layer is presented with very low conductivity.
2- Revising the geology and hydrogeology conditions another general head is entered in the west direction parallel to Wadi EL- Farigh (the start of Miocene aquifer) to represent the recharge rates from Rosetta branch with specified head = 4 m and conductance of 936 m^2/d.
3- Upward leakage from the Nubian sandstone artesian aquifer in the southwest direction of the Moghra aquifer (Rizk S. Z. & D., 1991) presents as general head boundary with conductance of 110 m^2/d.

Figure (5) shows the domain of model and the boundary conditions.

6-5 The Calibration Process

The calibration process is defined as a continuous changing of the available parameters to obtain the best fit between the observed head values and the model-calculated values. Model fitting (also defined as history matching, parameter estimation and the inverse problem) is considered by some to be the most important step in modelling. The changing of the hydraulic parameters values within a reasonable range, so that the model can be accepted as a good representation of the physical system of interest, there are two ways to carry out this process first by using optimization scheme like PEST or doing it by trial and error (Doherty, J., 2010).

6-6 Steady-State Calibration

The calibration year in steady-state case is 1988, piezometer head map for this year is available although no well data is available, in this model both methods of calibration are used, firstly PEST is used to obtain the optimum values for hydraulic conductivity then to minimize the difference between the calculated and observed head, manually method is used, result of calibration process is illustrated in Figure (6) and table (1) summary Water Balance in the Moghra Aquifer for Steady-State Condition.

Table (1) summary Water Balance in the Moghra Aquifer for Steady-State Condition

Element	Input	Output
Storage (m^3/day)	0	0
Constant Head (m^3/day)	190.65	29360
Wells (m^3/day)	0	0
Drains (m^3/day)	0	0
Lake Seepage (m^3/day)	0	0

Recharge (m^3/day)	0	0
ET (m^3/day)	0	0
River Leakage (m^3/day)	0	0
Stream Leakage (m^3/day)	0	0
Surface Leakage (m^3/day)	0	0
General-Head(m^3/day)	44027	14860
Total m^3/day	44218	44220

7- Model application

Main objective of the paper is to evaluate the potentiality of Moghra aquifer under the stress of Million and Half Fadden project wells, according to Groundwater sector (MWRI 2016), reclamation of 170000 Fadden depending on the groundwater will be a part of the National Project Figure (7). According to the Groundwater sector (MWRI 2016), the quantity of water demand for one Fadden is about 4000 m^3/year, so the expected total water demand for the proposed area is about 476 $x10^6$ m^3/year. The already executed wells number equal to half of the total number, hence actual total discharge from wells is $233.3x10^6$ m^3/year.

7-1 Proposed scenarios for aquifer management

To secure more effective water management and national planning, and a higher level of sustainability and continuity of development and progress a four proposed scenarios will be carried out to show the effects on the head of Moghra aquifer, three observation points are chosen to present the results.

First scenario: Determination of the drawdown corresponding to the total water withdrawal from wells of the project will cause undesirable results, the results indicate that some areas of the project will be dry and max. Drawdown will be 369 m after 50 years, Figures (8).

Second scenario: Decreasing the pumping rates from wells by 50 % and calculating the corresponding drawdown (discharge of total wells $=116.640x10^6$ m^3/year) during the coming 50 years, the corresponding drawdown is shown in Figure (9).

Third scenario: Decreasing the pumping rates from wells by 70 % and calculating the corresponding drawdown (discharge of total wells $=70x10^6$ m^3/year) during the coming 50 years, the corresponding drawdown is shown in Figure (10).

Fourth scenario: Dividing the working wells into three groups with the consideration of decreasing the third group which is near to the Nubian recharge by 70% of the discharge rates Figure (11), the results shows that no dry area is found, Figure (12).

The comparison between the four scenarios is shown in the next table after 50 years.

Observation No.	Drawdown (m)			
	Scenario (1)	Scenario (2)	Scenario (3)	Scenario (4)
Ob-1	369	201	113	348
Ob-2	379	206	116	356
Ob-3	dry	dry	165	361

The scenarios show that the wells near to the recharge from the Nubian Aquifer is the most effected, so it is recommended to decrease the rates of this wells.

8- Conclusion and Recommendation

Three dimensional model is developed to create a steady-state calibration model for Moghra aquifer which is located in the North portion of the Western desert, the groundwater flow is the main target for the calibration process, and the estimated parameter is the hydraulic conductivity and the observed values was collected from RIGW map for year 1988. Operating wells of Million and half Fadden and showing the effects on the aquifer are predicted, the authors proposed different scenarios for management reclaimed areas. The first one is to operate the wells with the total capacity. The second scenario is to decrease the withdrawal rates by 50 %. The third one is to decrease the rates by 70 %. The fourth scenario is consider that the wells were divided into three groups, with the withdrawal rates of the first two groups and the reduction in the third group by 70%, which reduced the presence of dry areas, The first and second scenarios produce dry areas especially near the compensation coming from the Nubian aquifer because the recharge rates is less than the discharge rates. The simulation of the last scenario was the suitable, to extend the life time of the aquifer. It is recommended to use discharge rates less than 50% of the designed rates.

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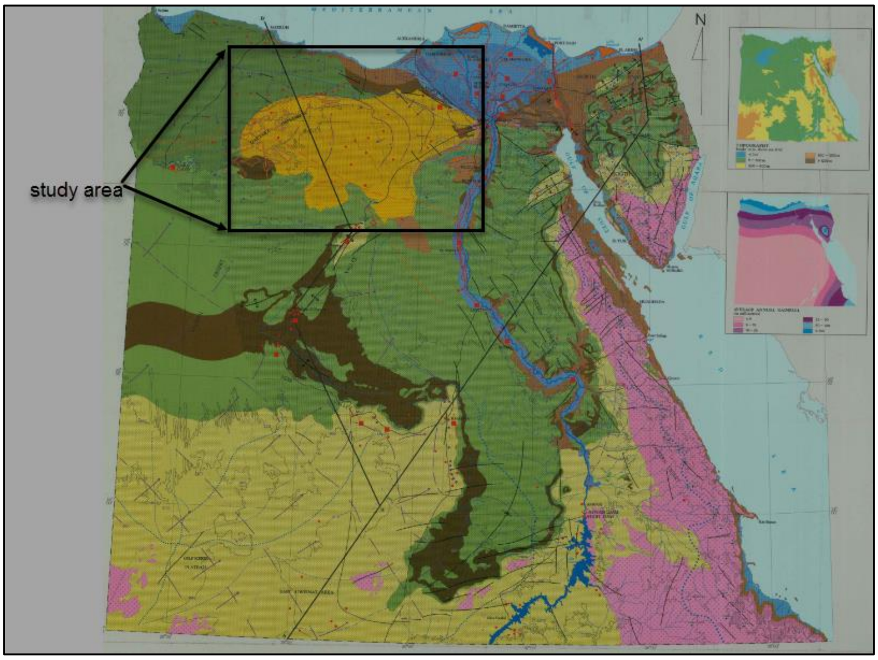

Figure (1) Location of Study Area

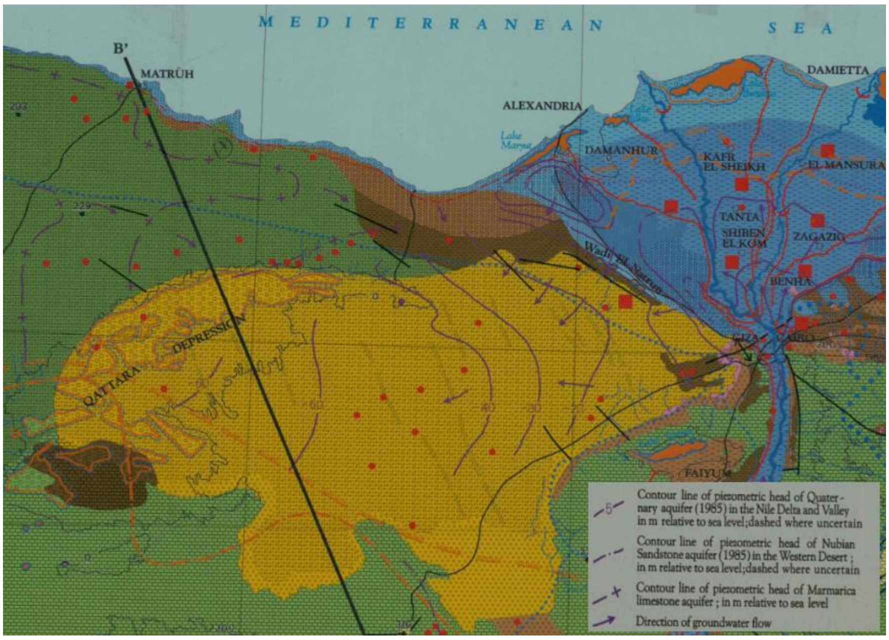

Figure (3) Piezometric head map (levels from 0 to -60) after (RIGW, 1988)

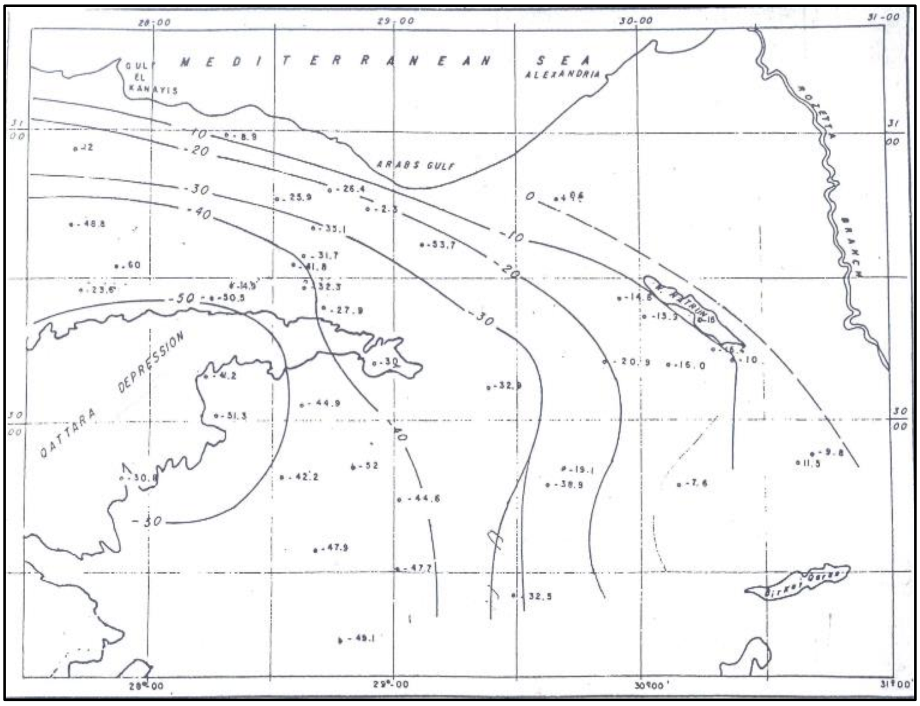

Figure (4) Piezometric Head Map of the Moghra Aquifer after (Ezzat M.A., 1984)

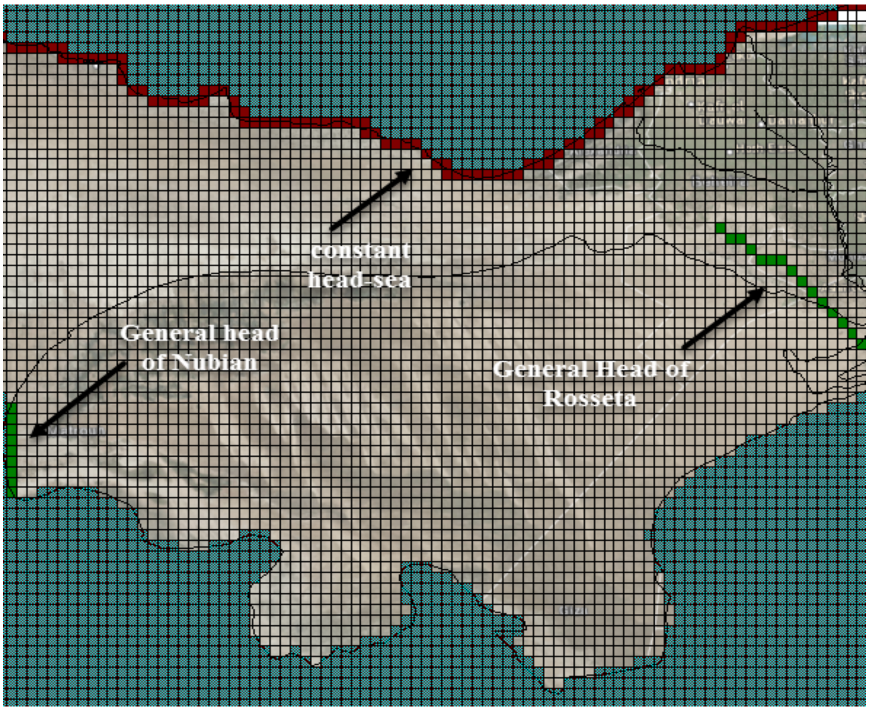

Figure (5) Mesh discretization for the Moghraa domain and boundary conditions

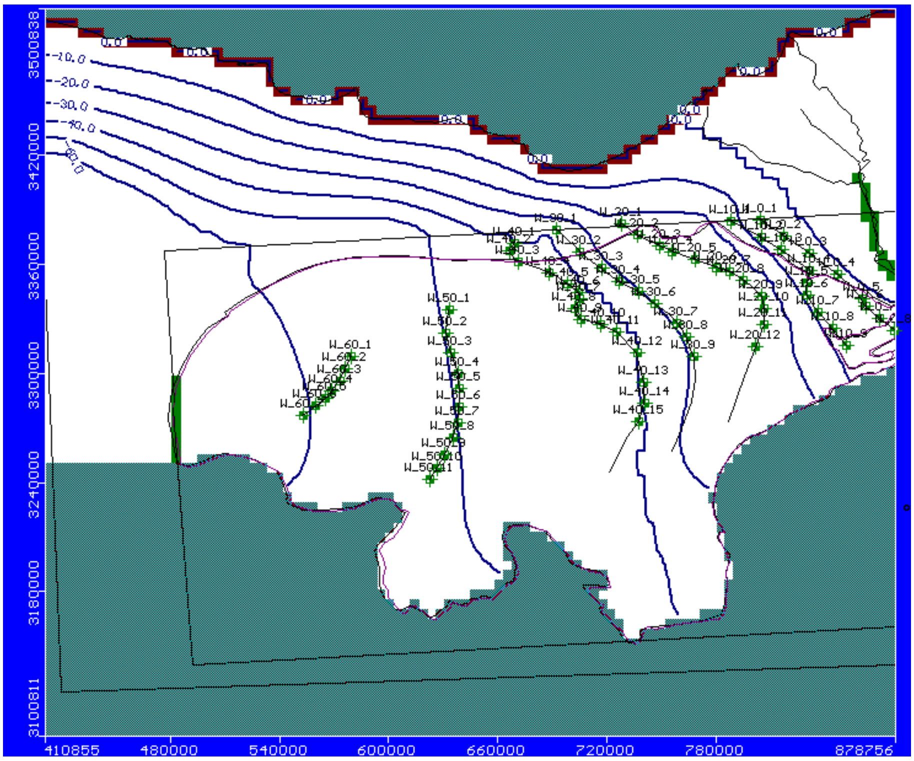

Figure (6) contour map of observed head map (1988) and calculated equipotential lines simulated from MODFLOW

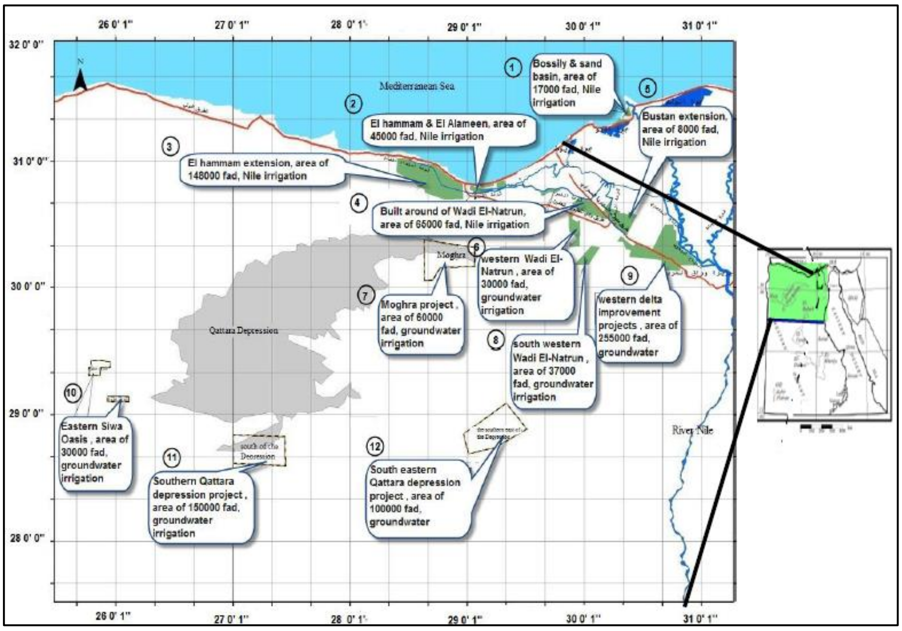

Figure (7) Map of the proposed strategic horizontal expansion plan in the North Western of Egypt, with scale 1:1,933,828, HES- MWRI, 2014 after (Abbass, S.Z, 2017)

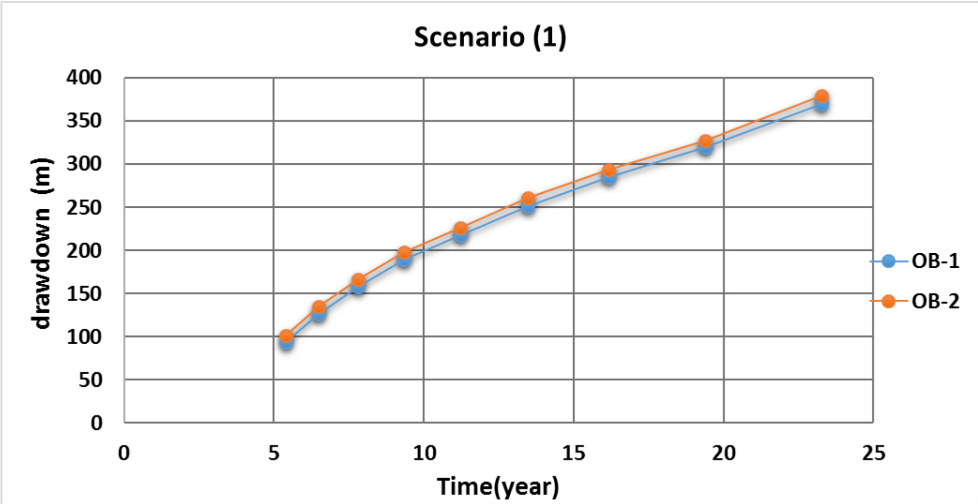

Figure (8) Drawdown at observation (ob-1, ob-2) due to scenario 1

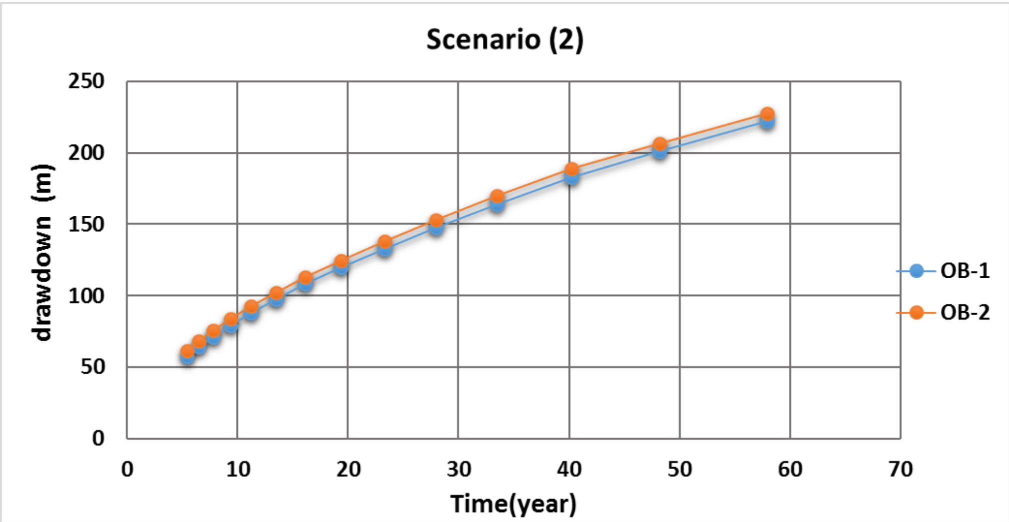

Figure (9) Drawdown at observation (ob-1, ob-2) due to scenario 2

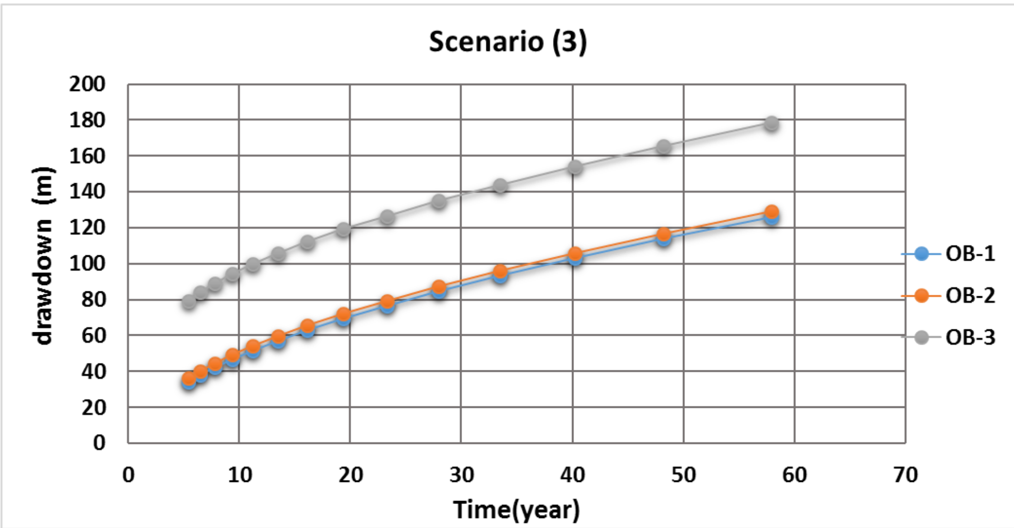

Figure (10) Drawdown at observation (ob-1, ob-2, ob-3) due to scenario 3

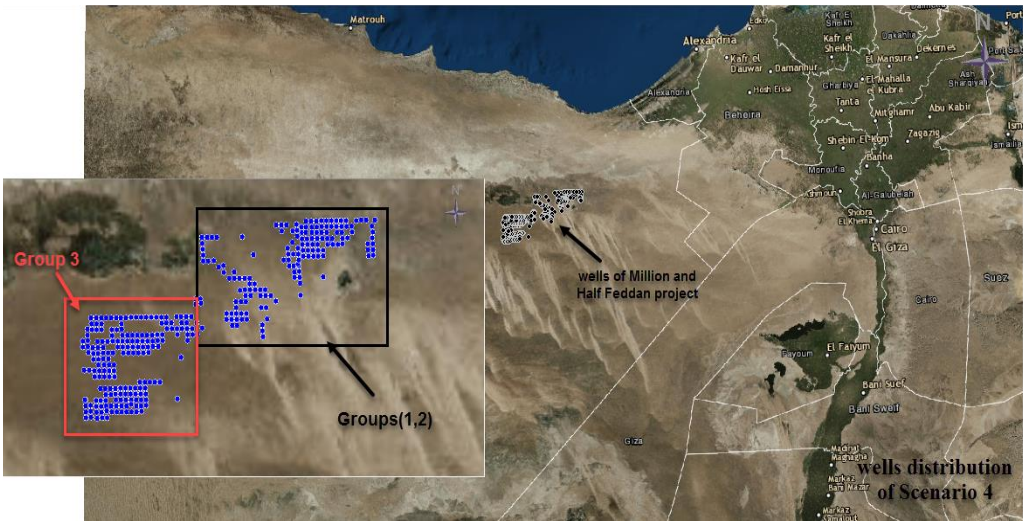

Figure (11) Well Distribution due to scenario 4

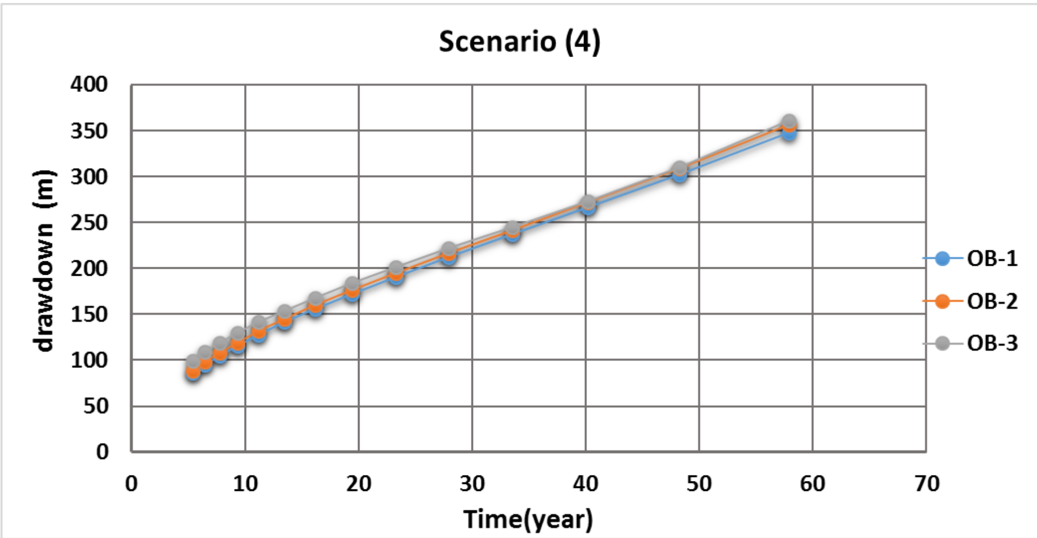

Figure (12) Drawdown at observation (ob-1, ob-2, ob-3) due to scenario 4