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Groundwater Levels Evaluation in AL-Khoms City

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الملخص

تقع مدينة الخمس في منطقة شمال غرب ليبيا، وتبعد عن العاصمة طرابلس حوالي 120 كم. تتأثر منطقة الخمس بمناخ البحر المتوسط في الشمال وبالمناخ الصحراوي في الجنوب. تعتبر المياه الجوفية المصدر الرئيسي للمياه في مدينة الخمس حيث تعتبر قلة الموارد المائية بالمنطقة مصدر قلق.

أن هذه الورقة العلمية تبحث في إمكانية تأثير تغير منسوب المياه الجوفية على منشآت تخزين المواد النفطية في المنطقة التابعة لشركة البريقة، في هذه الورقة العلمية تم تقييم منسوب المياه الجوفية لمنطقة الخمس اعتمادا على المعلومات المتوفرة وذلك من اجل التأكد من عدم تأثير منسوب المياه الجوفية على الاعمال الانشائية لمحطة تخزين الوقود بشركة البريقة.

تمت عملية التقييم باستخدام النموذج العددي MODFLOW حيث تمت معايرة مناسيب المياه الجوفية اعتمادا على منسوب مياه أبار المراقبة.

بعد معايرة النموذج تم اعتماد سيناريوين الأول يفترض أن قيمة المياه المسحوبة تعادل الاحتياجات القصوى للسكان والزراعة، فيما يفترض السيناريو الثاني ان قيمة تغذية المياه الجوفية تضاعفت.

تم ادخال بيانات أبار الضخ للنموذج وتمت المحاكاة وكانت نتيجة المحاكاة ان منسوب المياه الجوفية ينخفض باستمرار نتيجة لأن قيمة الاستهلاك الحضري والزراعي تفوق قيمة التغذية الواصلة للخزانات الجوفية.

وفق هذه النتائج يمكن لشركة البريقة إنشاء محطة تخزين وتوزيع الوقود دون أي قلق من ارتفاع منسوب المياه الجوفية.

الكلمات المفتاحية: الخمس، المياه الجوفية، النموذج العددي، آبار ، ضخ

A B S T R A C T

Al-Khums city is located in northwestern of Libya, approximately 120 km from the capital, Tripoli. The Al-Khums region is influenced by a Mediterranean climate in the north and a desert climate in the south. Groundwater is the main water source in Al-Khums, and the scarcity of water resources in the region is a concern.

This research paper investigates the potential impact of groundwater level changes on the oil storage facilities in the area belonging to the Brega Oil Marketing Company. The paper assesses the groundwater level in the Al-Khums region based on available data to ensure that groundwater levels will not affect the construction of the Brega Oil Marketing Company's fuel storage terminal.

The assessment was conducted using the MODFLOW numerical model, calibrating groundwater levels based on the water levels of monitoring wells.

After calibrating the model, two scenarios were adopted. The first scenario assumes that the water withdrawal rate equals the maximum needs of the population and agriculture, while the second scenario assumes that the groundwater recharge rate has doubled.

Data from the pumping wells were inputed into the model, and simulations were performed. The results showed that the groundwater level is continuously decreasing because urban and agricultural consumption exceeds the recharge rate of the aquifers. Based on these results, Brega Oil Company can establish a fuel storage and distribution terminal without any concerns about rising groundwater levels.

Keywords: Al-Khums, groundwater, numerical model, wells, pumping

1. Introduction

When water is present at depths close to the ground surface, it can negatively affect the stability and durability of structures. The impacts are determined mainly by the level of the water table, soil properties, water quality, as well as the nature of the structures themselves. Elevation of water table is rarely constant; it changes according to withdrawal and recharge rates. It is affected largely by the type of aquifer (confined, unconfined, artesian, etc.). Withdrawals are calculated according to the nature and intensity of water-demanding activities while recharge is determined by the intensity and frequency of rainfall, climatic factors and watershed characteristics.

Therefore, the study of groundwater hydrogeology is very important for the suitability of the site and the sustainability of the surrounding area.

2. Description of study area

The studied area is located near AlKhums city (east direction). This location is at the eastern apex of the Jefara Plain where the Mediterraneansea meets the Western Mountain (Figure1).

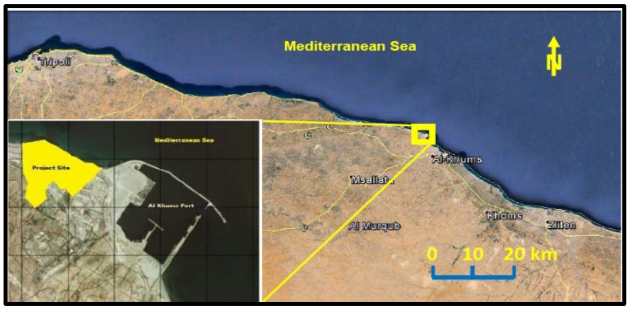

Figure 1: Location of Alkhoms Area

2.1 Geology

The Jefara Plain can be divided into three parts, all covered by Quaternary sediments, with some limestone hills of the Azizia Formation. These parts are: at north the coastal strip, at middle the central strip, and at south the foothill strip.

The coastline connects the sea cliffs, composed of calcarenite, covered by coastal sand dunes and brown silt of the Jefara Formation. This line extends to the south for a distance ranges from 10 to 20 km and its low topographic area covered by sebkha sediments.

The middle part extends from southern boundary of coastal strip up to 55-85 km, and the elevation in this part vary from 0 to 130m above sea level. Its harmonies are distributed through the dolomitic limestone outcrops of the Azizia Formation, which rises approximately 100 metres above sea level.

2.2 Groundwater Hydrology

The main groundwater aquifers in the coastal area of the Jefara Plain are located in Quaternary, Tertiary, Cretaceous and Jurassic geological formations. All of These aquifers formations located in Basin of Jefara Plain and Basin of Ghadames-Hamada (Figure 2).

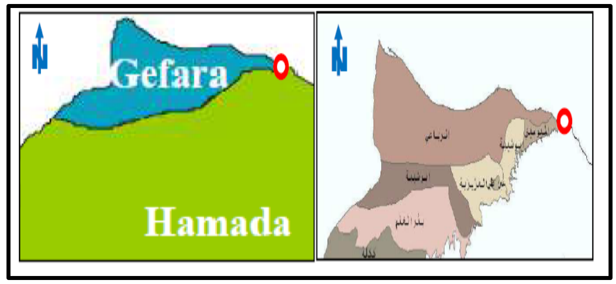

Figure 2: Hamada and Jefara Formations

The formations of Triassic aquifers, Quaternary, Upper Cretaceous, and Miocene, are unconfined in the coastal area; they are recharged from runoff and rainfall, and they are renewable aquifers.

Lower Cretaceous, Triassic, Cambro-Ordivician and Tertiary aquifers lying in the southern parts of the Jefara Plain and the Hamada are non-renewable [1].

The geological formations of these aquifers shown in Figure 3. It is the Miocene – Quaternary unconfined aquifer that is of significance to the Project Site suitability assessment, the water level in the the aquifers reaching several hundred meters below the ground surface at the project Site. Figure (3) showing main hydrogeologic and hydrologic characteristics of this aquifer.

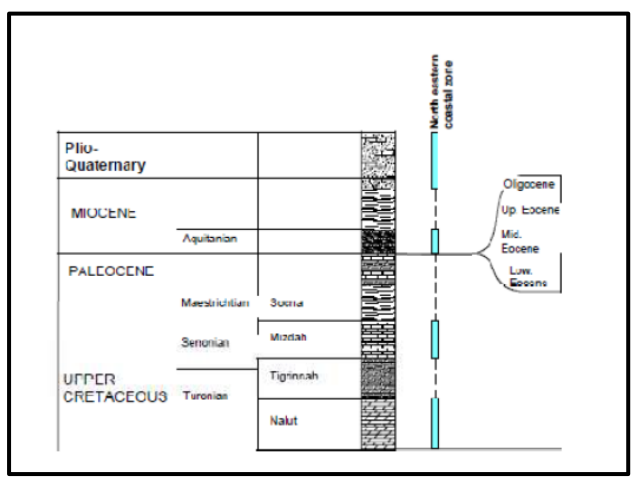

Figure 3: aquifers and their geological formations [2]

2.2.1 Quaternary-Tertiary (Mio-Plio-Quaternary) Aquifer

The Quaternary-Pliocene-Upper Miocene (Meo-Plio-Quaternary) Aquifer (also known as the Upper Jefara Plain Aquifer) occupies the upper strata covering the central and northern Jefara Plain; it is exposed to the land along the coast to form an unconfined aquifer. “The Quaternary sequence comprises the Pleistocene Jefarah and Gargaresh formations; overlain by Holocene soils and sand dunes. The Pre-Quaternary (Mio-Plio) substrate is represented by Cenomanian dolostone (the Sidi As Sid Formation) and/or Middle Miocene limestone (Al Khums Formation)” [3].

The aquifer is knowing as renewable as it is recharged mainly by surface runoff and rainfall and from Nalut aquifer horizontal flow where waters lying to the south.

The aquifer is recharged by direct rainfall, surface runoff, and horizontally from Nalut aquifer, so it is knowing as renewable aquifer

The part of Mio-Plio-Quaternary aquifer which located between Zliten and Al Khums, is renewable and recharged by rainfall infiltration in addition to horizontal flow from Nalut aquifer. The Quaternary aquifer components are limestone, wind eroded sediments, and sandstone. Miocene rocks consist of limestone interspersed with clay, marl, and marly limestone.

The geological formations of the Quaternary aquifer include three formations, which are: Ghargaresh formations, Jefara, and.Qasr al Haj, They vary from gravels and fluvio-aeolian sands littoral sands and silts to Aeolian calcarenites in the coastal area.

The Quaternary aquifer (unconfined aquifer) thickness is varying from 35 - 155 m with a water saturated layer of 10 – 90 m.

The Jefara Formation starts with sandy conglomerates and shallow marine facies, moderately to well cemented massive sandy limestones; followed by well-developed cyclic repetition of nodular and platy calcretes.

The Gargaresh Formation parts are marine sediments which composed of white calcarenites with small quartz grains and shell fragments. They are exposed as cliffs on the coastline of the Mediterranean.

Well productivity ranges from 20 to 60 m3/hr and salinity varied from 1000 to 2000 mg/l). Along the coastal region, the saturated thickness of the aquifer varies from 10 to 150 m with a thickness of only 30 m, the transmissivity of the coastal region is 2 x 10-3 to 1 x 10-2 m2/sec and the storage coefficient ranges from 6 x 10-2 to 1 x 10-1 with TDS of below 1000 mg/L. The eastern part of the aquifer with good water quality is limited in extent to the coastal zone. Storage coefficients (S) is about (3*10-5 to 3.6*10-2) at Gharabulli and Ben Ghashir, respectively [4].

The unconfined aquifer also exposed to the pollution with infiltration from septic tanks widely spread in rural “unsewered” areas. Due to the relatively good water quality, quaternary aquifer is utilized heavily.

The Miocene aquifer formations are Middle and Lower Miocene. The Middle Miocene aquifer is 125 to 200 m thickness. This aquifer is confined located between two layers of clay and the recharge is coming by horizontal flow. At depths of 250-390 m The Lower Miocene aquifer is found at central Jefara and found at 485 m west of Sabrata. TDS ranged from 2500 to 4000 mg/L. This aquifer is Recharging from AlAzizia aquifer.

In the western part, the Lower Miocene consists of sandstone and limestone/sandstone conglomerates lying directly above and in hydraulic contact with the Abu Shaiba aquifer. The TDS are 2500 - 4000 mg/L. The storage coefficients and transmissivity for this aquifer are shown in table 1.

Table 1: Transmissivity and storage coefficients for Lower Miocene

Aquifer	Transmissivity	Storage coefficient
Middle Miocene	$5 \times 10^{-2} m^2/s$	1×10^{-3}
Lower Miocene, central western part	$5 \times 10^{-4} m^2/s$	
Lower Miocene, central northern part	$5 \times 10^{-3} m^2/s$	

In north-western Libya, the Miocene is represented by AlKhums formation (Middle Miocene) which overlies Lower Cretaceous rocks. This formation appears as an along the coastal areas of the Jefara plain extending about 20 to 25 kilometers southwards in unconfined aquifer in the region south of AlKhums. It is mainly consists of limestone, chalk, fine sand and oily clay. The depths of these layers are 30-300 m with a water-bearing layer depth of only 30 to 100 m. These layers are continuous hydraulically. Its thickness is 100 to 150 m [5].

The aquifers productivity is 20 m3/hr and the drawdown is 2-20 m/year. The TDS concentration is 2000 to 3000 mg/L increasing in areas with seawater intrusion. The aquifer relies heavily on rainwater infiltration for its recharge. The groundwater flow is generally away from the recharge area (west central) towards the north (main flow) and southwest (local flow).

3. Discharge

Several studies have been conducted to estimate groundwater withdrawal from the Jefara Plain.Table (2) is showing the estimation of Agriculture use and municipality use per year.

Table (2): Agriculture and municipality use/year. [6]

Estimation Date	Author	Agricul ture use Mm3	municipal use Mm3	Total Mm3
1959-1962	USGS	195	15	210
1972	GEFLI	313	65	378
1975	GEFLI	475	92	567
1978	SDWR	461	94	555
1980	GEFLI	483	91	532
1993	FAO	802	200	574

Within the Project area there is no springs but there is Ain Kaam (spring) located far from site by 20 km. The discharge from spring about 350 L/s; dissolved solids concentrations are 1400-2000 mg/L. Because of the Project site is on the coast line, this discharge can be neglected and is not likely to impact the water table under the project.

Evaporation losses may also be significant where the groundwater level is close to the surface. However, this is not the case for the Project site as indicated by piezometric levels of wells in the area.

Most of the groundwater withdrawals in the study area are for municipal and agricultural purposes, the latter being the most important in quantitative. Two types of agricultural water uses exist: 1) permanently irrigated fields with heavy groundwater extraction (estimated at 5000-9000 m3/ha/year, and 2) partly irrigated fields with moderate groundwater extraction estimated to range from 1500 to 3000 m3/ha/year (Pallas, 1978). The project area is considered to be of moderate extraction type with permanently irrigated areas constituting only a small portion of the total area.

Estimated abstractions from the aquifers in the area from AlKhuns to Tawergah in the year 2000 for agricultural and domestic uses are shown in Table 3.

The difficulty of obtaining information about the wells drilled in the study area makes it difficult to determine the annual withdrawal quantities through wells for irrigation and domestic supply purposes in the project area. An estimate will be possible upon collection of representative data on irrigated agricultural lands and well characteristics. Considering the depth of the wells, this extraction is mainly from the Mio-Plio-Quaternary aquifer.

Table 3: Abstraction from Different Aquifers within Jefara Plain [2]

Aquifer	Abstraction, million m3/year
Mio-Plio-Quaternary	57.00
Upper Cretaceous	40.60
Lower Cretaceous	6.00
Total	103.60

4. Recharge

Recharge to the Quaternary aquifers is from three sources as follows:

1. Direct infiltration from precipitation that infilterates down into the aquifers in areas where the aquifer is unconfined. It is also reduced by 90 % instead of cropped area increases. The infiltration recharge coefficient of precipitation is estimated to be 0-19 % of the total annual mean rainfall resources [7].
2. Recharge by runoff water infiltration from the streams in the region draining seaward that percolate into the ground along the wadi stream. It is assumed that the infilterated water will reach the water table of the aquifers. It is estimated to be 10-30 % of the runoff volumes infiltrating through the wadi beds in the spreading zones.
3. Inflow from groundwater aquifers in the south; the escarpment of Jabal Nafusa usually corresponds to the groundwater divide and therefore no inflow from the south except for two cases, namely, in AlAzizyah aquifer and in the eastern part of the Jefarah plain where the Mesozoic sandstones are in hydraulic continuity with those of the Suf Ajjin basin; here, the piezometric slope clearly indicates a flow direction from south to north. The inflow from Suq al Khamis to AlQusbat is estimated at 60 km length (of the front) x 1.25 to 1.7x10-3 (hydraulic gradient) x 10-2 m2/s (transmissivity) = 0.75 to 1.02 m3/s, i.e., 24 to 32 million cubic meters per year [3]

5. Groundwater Quality

The groundwater quality shown in Table 4, expressed as TDS, occurring in the various aquifers/formations located within the project area. Water quality, expressed in terms of TDS varies from 500 to 5000 mg/L. if TDS concentration more than 1000 mg/L then the water unusable for many purposes, the groundwater quality of the different aquifer in the Project Region is poor with exceptions in the Cretaceous aquifers.

Table 4: Typical Groundwater Quality of Different Aquifers Underlying the Project Region [6]

Aquifer	TDS, mg/
Mio-Plio-Quaternary	1000-5000
Upper Cretaceous	500-5000
Lower Cretaceous	500-3000

6. MODFLOW 2000 Description

MODFLOW-2000, is a Finite Difference computer program that numerically solves the three-dimensional ground-water flow equation for a porous medium.

6.1Governing Equation

Groundwater flow simulation performed by numerically solving the groundwater flow.

The groundwater flow equation can take many forms depending on the assumptions that are valid for the problem of interest. In most cases, it is assumed that the density of groundwater is spatially and temporally constant. To simulate groundwater flow in coastal environments, the assumption of constant density is not valid, as seawater contains a higher concentration of dissolved salts than rainfall, which is the primary source of aquifer recharge. Fluid density depends on dissolved salts.

Ground-water flow equation used in MODFLOW is partial-differential as:

$$\frac{\partial}{\partial x}\left(k_x\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(k_y\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(k_z\frac{\partial h}{\partial z}\right)+W = S_s\frac{\partial h}{\partial t} \ldots\ldots\ldots\ldots\ldots\ldots(6-1)$$

Where

k_x, k_y, and $k_z$are values of hydraulic conductivity along the x, y, and z coordinate axes, which are assumed to be parallel to the major axes of hydraulic conductivity (L/T);

h is the potentiometric head (L);

W is a volumetric flux per unit volume representing sources and/or sinks of water, with W<0.0 for flow out of the ground-water system, and W>0.0 for flow in (T-1);

S_s is the specific storage of the porous material (L-1); and t is time (T).

6.2 Aquifer Characteristics

The groundwater flow model built up of one layer. The ground surface topography was estimated from ArcGIS and the downloaded DEM maps. The lower elevations of the layer were taken where the layer thickness is 150 m. Figure 4 presents a plan view for the top layer of the modeled area after being interpolated by the model.

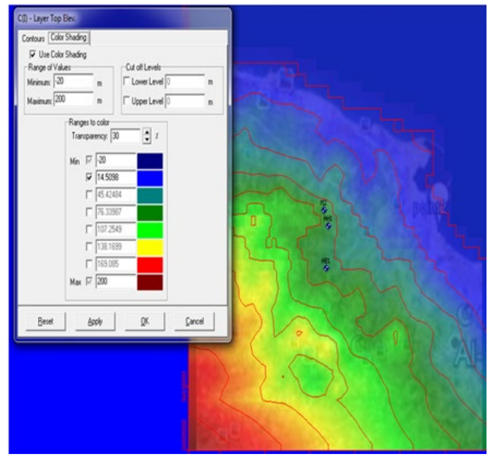

Figure 4: Plan view of the top layer elevations

6.3 Groundwater Flow Model Areal Extent

Regional model covered an area of 76 km2 as shown in figure (5).

Figure 5: Regional Model

The model domain consists of 56 rows, 40 columns and 1 layer; represents the Quaternary-Miocene unconfined aquifer (upper aquifer), the number of rows and columns are increased in areas where we need more accuracy.

Boundary Conditions for Steady State.

They are mathematical expressions that define the dependent variable (the head) or the derivative of the dependent variable (the flux) at the boundary of the problem domain. This step is very important in the model design. The boundary conditions in the created model here are assigned based on some head data from field measures as following:

North: zero head-constsnt boundary (sea level (Dirichlet conditions),

South: Constant head boundary with head = 2 m above sea level (Dirichlet conditions),

East and west: no-flow boundary (Neumann conditions). From the last boundaries we can conclude that the contour lines of the groundwater elevations are parallel to the south and north boundaries, then the flow direction is parallel to the east and west boundaries of the model domain which means no-flow boundary in east and west.

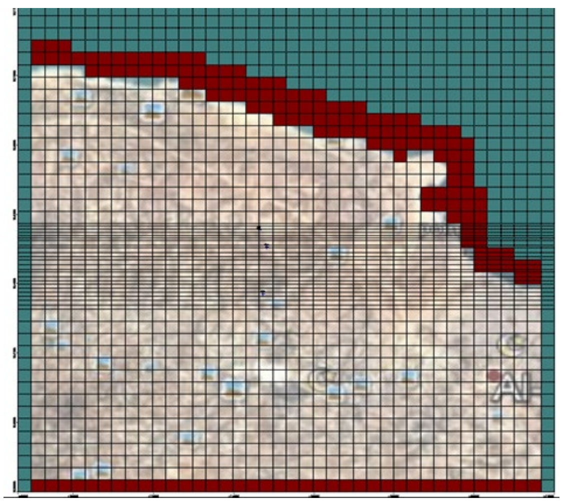

Figure 6: Constant head boundaries.

Table 5: Input parameters for the model.

The model grid	No. of aquifers	1
	No. of layers	1
	No. of columns and rows	40&56
Aquifer characteristics	Hydraulic conductivity	0.045-55 m/d
	Total porosity	30%
	Effective porosity	15%
	Specific storage	0.004 m-1
	Specific yield	0.0085-0.48

In Figure (7) we can see the input hydraulic conductivity values.

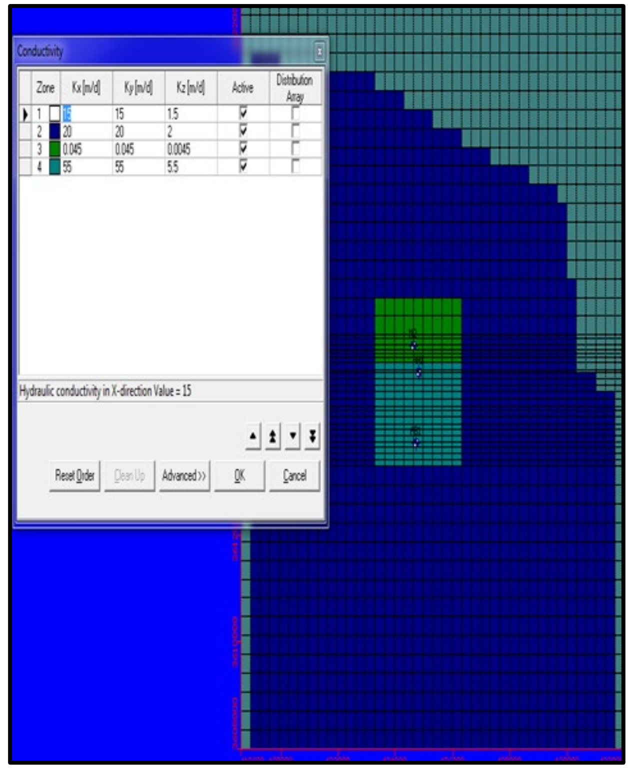

Figure 7: Hydraulic conductivity distribution

6.4 Recharge components

Surface recharge is spatially distributed along model grids (Neumann boundary condition) the "Recharge" boundary used as depths in mm/year for each cell. Surface recharge refers to the volume of infiltrated water that crosses the water table and becomes part of the groundwater regime. In the study area, recharge reflects the amount of infiltration by precipitation rates and infiltration by return flow after irrigation and from water networks. Recharge to the top layer expressed as mm/yr. transferred to discharge from multiplying the recharge depth in cell area. The recharge estimated by NCB & MM on 1993. The net recharge for Jefara Plain is 3.76 Mm3 resulted of recharge from rain, irrigation return flow.

7. Model Calibration

7.1 Introduction

MODFLOW model used as a management tool for the studied area.

The main parameter controlled the steady state calibration is aquifer hydraulic conductivity where is altered until the piezometery matches the observed piezometry.

7.2 Steady State Calibration

Calibration is a trial-and-error adjustment of aquifer parameters until the model results matches the field values. In general the model calibration is a base to design a steady-state model for the head distributions to be used as an initial condition for a transient-state simulation after applying different scenarios on it.

The steady state model was simulated for the year 2016. In this year a relatively comprehensive set of agricultural and municipal abstraction data are known.

Steady state calibration for the flow model was achieved by comparing the hydraulic heads obtained from available groundwater levels of the upper aquifer and the calculated hydraulic heads of the MODFLOW, data for 2016 from contractor used to calibrate the head in observation wells as shown table (5). During calibration, horizontal and vertical hydraulic conductivities values were adjusted in sequential model runs to match the simulated heads and measured head, the calibration was done by the help of PEST (inverse modeling) by MODFLOW v.4.2. Inverse modeling is the processes of adjusting model inputs until the optimum set of inputs are determined for a particular condition; table (6) shows the results of the steady-state calibration, and table (7) gives Summary of steady-state calibration statistics in 2016 model.

Table 6: Data of observation wells

Well No	x	y	head
AH1	424826	3615057	1
AB1	424736.4	3613715	1
M2	424623.5	3615553	2

Table 7: Summary of steady-state calibration statistics in 2016 model

Time:	Steady state
• Num. of Data Points :	3
• Max. Residual:	0.116 (m) at obs. 1134
• Min. Residual:	0.036 (m) at obs. 1115
• Residual Mean :	0.07 (m)
• Abs. Residual Mean :	0.07 (m)
• Standard Error of the Estimate :	0.024 (m)
• Root Mean Squared :	0.078 (m)
• Normalized RMS :	7.7 (%)
• Correlation Coefficient :	0.999

Figure (8) showing the comparison of simulated results against observed water level values. The modeled values show a correlation coefficient of 0.99 with the observed values. The calibration results for the groundwater levels in the steady-state case are satisfied with a RMS value of 0.078 m. Figure (9) summarizes the simulated water budget for study area. Under the steady-state conditions, the average inflow to the system is approximately 4.85 Mm3. About 4.85 Mm^3 leaves the model domain.

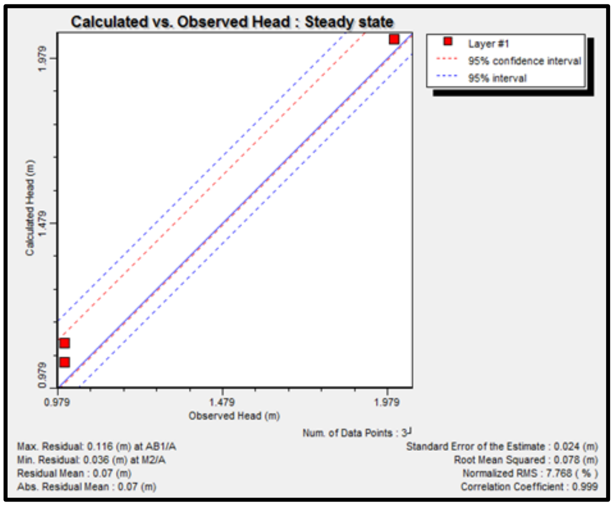

Figure 8: Calculated vs. observed piezometric levels results

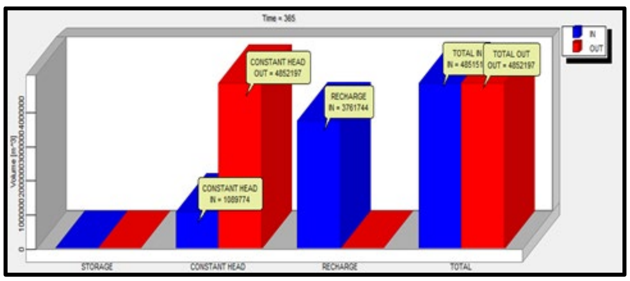

Figure 9: water balance

8. Predictions

In this section, two scenarios will be applied in the model to describe the model sensitivity to pumping for municipal and agriculture uses, and to recharge variability. Figure (10) shows the spatial distribution of the pumping wells

Figure 10: wells distribution

Table 8: Different simulated scenarios by the MODFLOW 2000 & MT3DMS model.

ID	Description	Notes
Sce.1	Pumping for both agriculture & municipal uses as predicted.	Reference scenario
Sce.2	Effect of recharge (double value).	

8.1 Scenario No.1

In this scenario, the model will run with abstraction as predicted in chapter of model description.

The head contours after 20, 45 years are shown in figures (11), (12).

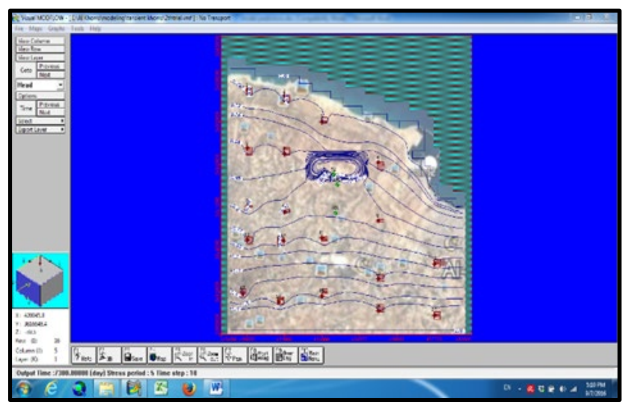

Figure 11: water tables contour after 20 years

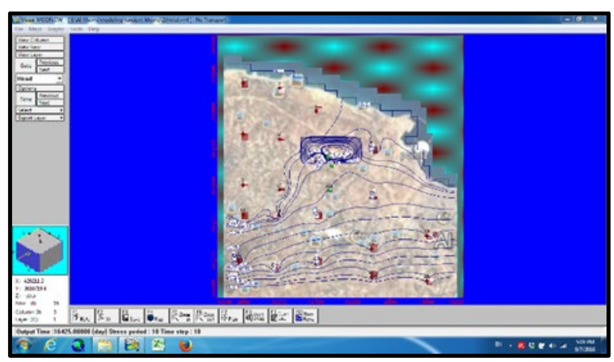

Figure 12: water tables contours after 45 years of simulation time

8.2 Scenario No2

In this scenario, the effect of recharge variability will be considered as double value of original recharge.

Figures (13), (14), showing the head contours after 20, 45 years respectively.

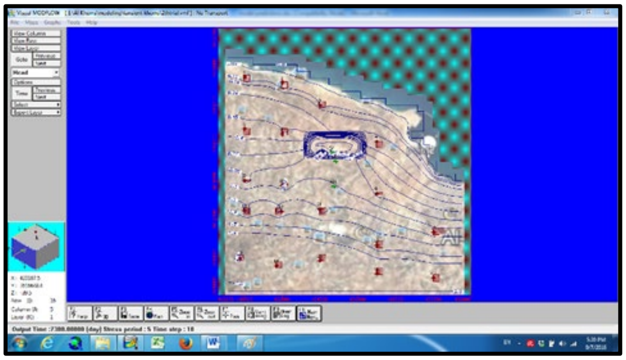

Figure 13: water tables contour after 20 years of simulation time

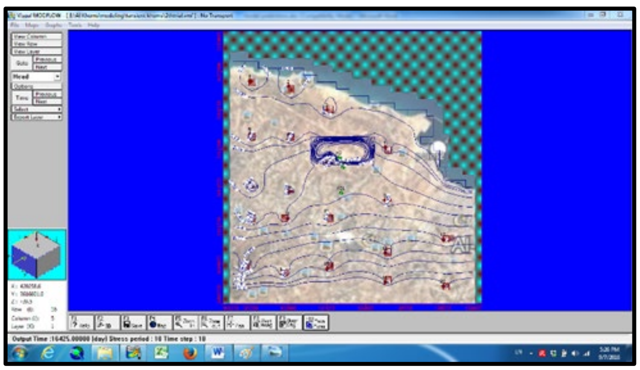

Figure 14: water tables contour after 20 years of simulation time

Results of scenario 2 indicated increasing in the head at observation points.

Conclusions

After calibrating the numerical model by inputting topographic data, aquifer thickness, and hydraulic conductivity coefficients, for steady-state. two scenarios were applied. The first scenario involved pumping a potential volume of water equal to the maximum population and agricultural needs, while the second scenario involved the same pumping volume but with double the surface recharge.

The results in both cases indicated that the groundwater level continued to decline throughout the 45-year modeling period.

Based on the above result, the storage structures of the Brega Oil Company will not be affected by the groundwater level because it is decreasing and falling.

The maximum GW levels lowering values for the scenarios considered indicated that the first scenario has big effect on GW levels lowering.

9. References

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