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Evaluation of the Hydrogeological Situation of the Groundwater Aquifer Caused by Creating Urget Wells in Aleppo City

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ABSTRACT:*During the years of the war, Aleppo suffered frequent water cuts from the main sources coming from Al Khafsa pumping station on the bank of AL-Assad Lake. This led the Ministry of Water Resources to work to find urgent solutions to secure water for citizens by digging 150 emergency wells as a first step in the western parts of the city of Aleppo, and after the Syrian Arab Army regained the eastern parts of the city, the Ministry of Water Resources has been drilling 51 additional wells to be enetered within an emergency plan.*
In this research, we located and linked the wells with the city's organizational chart using GPS. The hydrogeological situation of the well drlling area was also studied through the creation of hydrogeological sections of these wells using the Rockworks 17 software depending on GIS.
We collected and documnted all data related to the wells invested in the study area based on the records of the pumping experiments for each well. We continued taking the periodic measurements and readings of the water levels in the wells studied from the middle of 2016 till now. Hydrographs of the groundwater tables were prepared for wells with continuous monthly measurements.
We are resuming the collection and documentation of all data related to wells that were later drilled in the esatern parts of Aleppo to be studied with wells in the eastern areas of the city. Using the equivalent well theory, which is an application of the principle of collection of effects, we can claculate the percentage of the effect of the group of wells in the study area by calculating the effect of the equivalent well.
There are some wells that penetrate more than water aquifer. This is due to the fact that the studied area cxonsists of more than one hydrogeological formation containing two levels of water or more. In-depth description of the hydrogeological chrcaterization, determination of the terminal conditions of the study area, the geometrical dimensions of the studied water carriers and their hyrdaulic properties, we have been able to conecive some of the possible changes to them as a result of the investment.
In this pahse of research, we have reached some conclusions that will enable us in modulating the aquifer, which can help in the development of the safe investment system and the possibility of predicting the depletion of aquifers within the city due to severe pumping of water from these wells.

Keywords: *Hydrogeology, wells, safe pumping, aquifer Basin, RockWorks 17*

1. Introduction

Aleppo city suffered from critical water supply problem during the few last years as a result of having the entire water resources and its related facilities and plants captured by terrorist groups, which made the ministry of water resources take some meaures to find urgent and emergency solutions to alleviate the suffering of citiznes through:

- Setting an urgent rescue plan to provide alternative water resources in the city.
- Drilling of 150 emergency wells at the first stage distributed within certain parts of the city [1]

After the Syrian Arab army regained the whole city of Aleppo, water company in coordination with the directorate of water resources drilled additional 51 wells to be included under the alternative emergency plan [2]

2. Research justifications

Due to the water crisis experienced by Aleppo city as a result of the interruption of water supplies which are dilevered through water pipelines coming from Alkhafsa pumping station on the Euphrates river and the drilling of emergency wells and as a result of the injustice of excessive and unreasonable consumption, there must be a study to be set for the mechanism of exploiting these wells in correct scientific method through:

- Verification of the effiecieny of these wells.
- Knowing the reasons of having some wells out of service.
- Explain the turbulent behavior of some wells.
- Lack of clear vision of water pumping program which achieves a safe exploitation of the wells.
- Lack of previous hydrological study for the groundwater aquifer in Aleppo city which we will figure out in our research.
- Lack of mathematical model which hardens the possibility to achieve the establishment of safe exploitation system and to compensate the depleted groundwater aquifer.

Based on the above the idea of preparing a comprhensive study aims to conserve the groundwater aquifer within Aleppo city and prevent its depletion and to work for the setting of optimal safe exploitation of extracted groundwater without damaging the groundwater aquifer.

3. Reasearch improtance

The research improtance is underlined by the following:

- Allowing the set of well exploitation regime which enable the water competent authorities to place a proper operation mechanism for the pumping operations of the studied area.
- Determination and monitoring the strategic storage of the first and second aqueous carrier and prediction of the future of the aquifer in Aleppo city.
- Preparing an integrated comprehensive hydrological information system for groundwater using computer technqiues and conencting it with GIS.
- Analysis the cause of failure of some wells drilled and equipped after a short period of investment and prediction the number of well which will be out of service later and specifying the remaining time for that.
- Setting recommendations and sugegstions for optimal investment of the groundwater.

4. Purpose of the research

The goals of this study can be summarized as the following :

- Preparing a mathematical model which allows to connect wells` flows with the levels of the first and the second water carrier tables, and this model will be applicable for more general and comprehensive cases.
- Determination the future investment system of the wells.
- Making calaculations and studies to obtain the map of maximum and minimum groundwater equal levels.

- Future forecast for the possible variations of the aquifer content as a result of pumping out water from this area.

5. Reference studies

The reference studies will be displayed according to the follwing guidelines:

The geological studies [13,14,15,16], hydrogeological studies [11,12], mathematical modeling of aquifers [3] and software packages used in the modelling of aquifers [2].

5.1 The geological and hydrogeological studies:

The geological and hydrogeological studies started in Syria during the 2nd quarter of the 20th century where Aleppo aquifer had a great share of these studies which can be summarized as the following:

5.1.1 Geological studies:
The first study was performed by Duptrier in 1933 where the Syrian geologic map was prepared [9] at a scale of 1/1000000 and was updated in 1943-1945.

5.1.2 Hydrological studies:
Many companies and researchers performed hydrological studies and the most important one was performed by the directorate of aquifers in cooperation with Salkhouz Prom Export during the period 1974-1978. They performed hydrological studies and investigations for the western part of Syria including Aleppo's aquifer and included the drilling of investigation wells and performing pumping experiments on them.
They also did the required geophysics measurements and chemical analysis of water samples in addition to the preparation of hydrological maps.

5.2 The mathematical modeling of aquifers:
There are many studies which performed modeling of the aquifers including:

1. Project of modernization of hydrographic aquifer study within the territory of the Syrian Arab Republic - phase two, the public organization of water resources in Aleppo [1], 2001.
2. Study the modeling of Alzabadani area in Barada and Awag basins for a surface area of 140 km^2 which was performed by the German institute for natural resources and earth sciences BGR in cooperation with the Ministry of Irrigation in Syria [3], 2007.
3. Study of the water resources in the middle east - case study: modeling of groundwater in the southwestern parts of Aleppo basin in Alzerbeh area which was performed by Freiburg institute for geological sciences FOG, 2015

5.3 The available software packages:
There are several software packages which are used in modeling for water aquifer basins such as: ArcGIS, GPS, RockWorks, Excel, MODFLOW and we used in this study the software package RockWorks which allow the input of all available information of the studied parts and linking them with the above software packages and we will use MODFLOW later in this study. Fig (1) shows a sample of the job performed by the mentioned software packages for the description and

characterization of some hydrogeological sections for some wells and according to their designations [17].

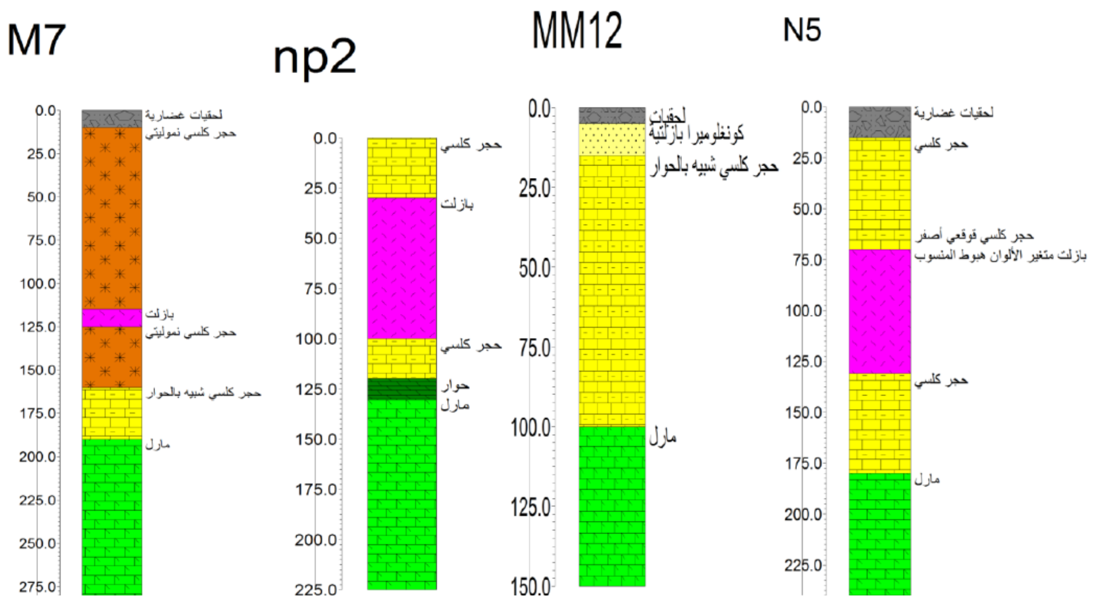


Figure.1: The lithological description / designation of the studied wells in Aleppo.

6. Method and materials

In this research we worked on:

6.1 Phase of collection of the required data and necessary information for the research.

This phase is one of the main research phases which took a long time, and included the collection of documents, information, data and periodic measurements for the groundwater levels and the reports of pumping tests of the drilled wells under the emergency plan.

The number of the emergency wells drilled in Aleppo is 251 wells – figure (2)

The information about the lithological description of the wells are available and there are periodic water level measurements, and also there are information concerning the wells on which the pumping tests were performed and investment information (wells which were operated in the city according to specific operation hours - shifts).

According to documented information the total number of wells is 332, which are distributed as follows:

1- Worshiping houses: 87 wells.
2- Schools and hospitals :29 wells.
3- Private wells :216 wells which were exploited and operated by their owners to serve the people during that period.

Then the total well number which were serving the population within Aleppo is about 583 wells.

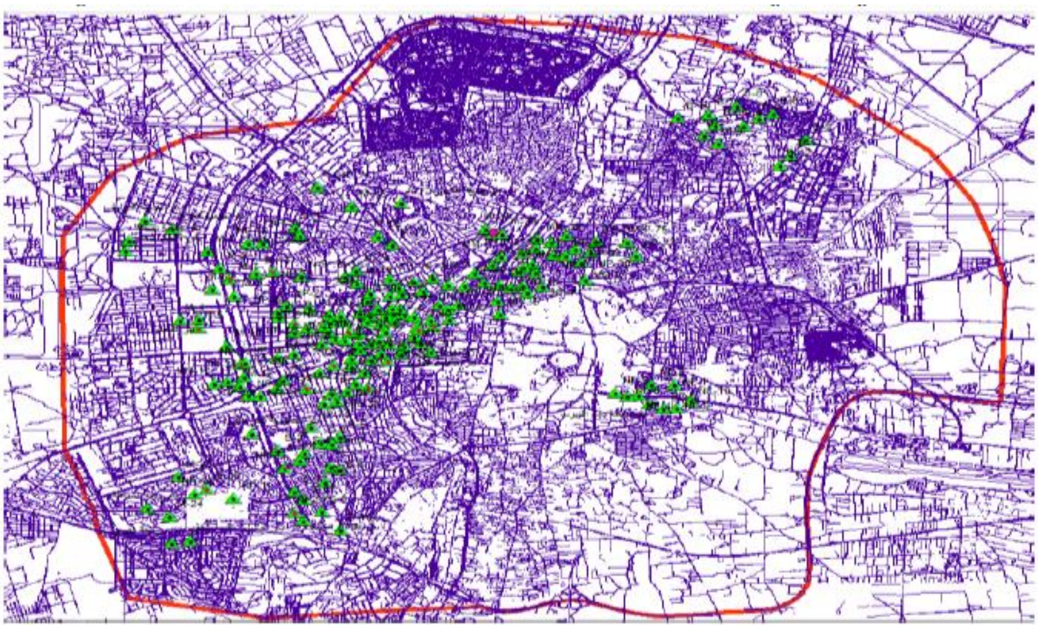


Figure.2: Plan of the emergency wells locations in Aleppo

6.2 Exploring the location of wells and having their coordinates and placing them on a map at suitable scale and connecting it with the GIS:

Relying on the geologic map of Syria we linked the organizational map of the city using GIS software through the reduction of the map and matching it with the geological sections of the studied area [9] for displaying the well location within the city, fig (3).

Figure.3: The geologic map with the wells and the organizational map of Aleppo

From the above figure we note that the wells are distributed within the city center and are located on the bed of Quake river within quaternary combinations, while most wells are located on the 2nd water carrier (Paleogene) except the drilled wells in high areas such as Alzebdieh and Alizaa where these wells are located in the areas of Neogene stratifications and also all the wells in western Aleppo are located within the 1st water carrier (Neogene) [18] as shown in fig (4).

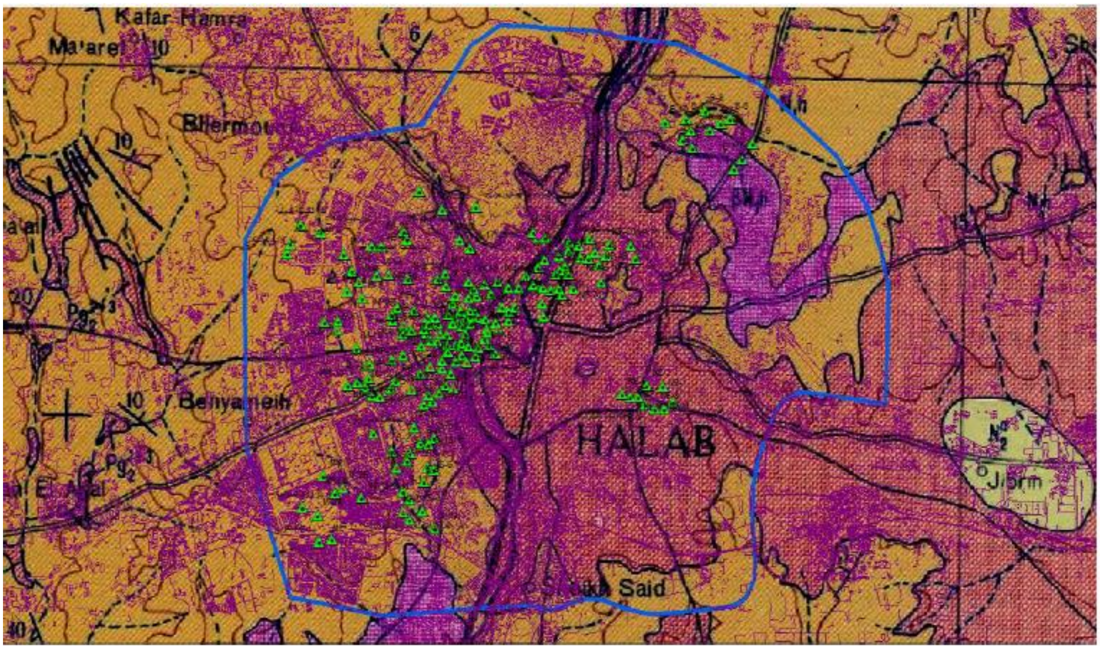


Figure.4: The Syrian geologic map with the drilled wells under the emergency plan in Aleppo

From the above figure we see that the leveling line 400 m is separating the Neogene carrier in the northwestern area from the Palogene carrier and whenever we go high over ground surface we return back to Neogene and also there are wells which their water is exploited which belong to more than one hydrologic structure, i.e. a combination of two water- carrying levels (mixed water) [18].

6.2 Preparation of a 3D geologic model for the studied wells using RockWorks software:

In this stage we used RockWorks software [17] to input the layers composing each well based on drilling. We were able to deduce the 3D geologic model for the studied area after connecting the similar strata among them (automatic matching) as shown in fig (5).

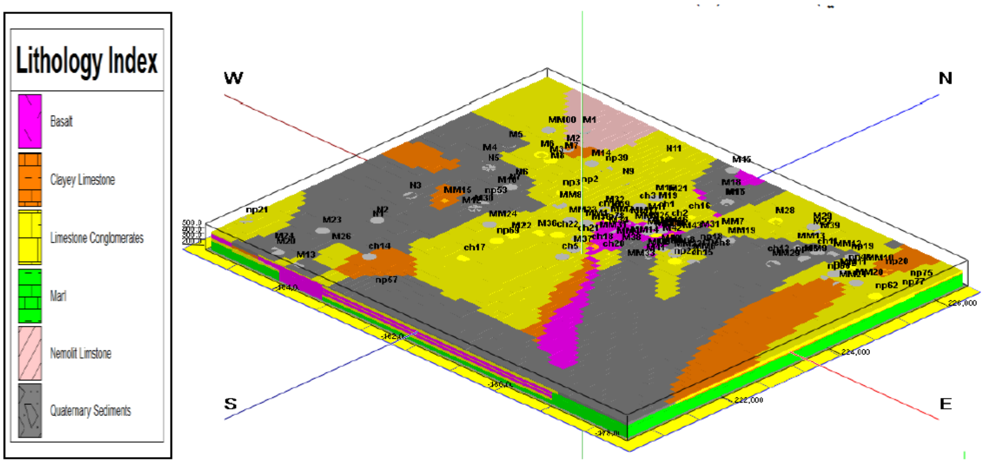


Figure.5: The 3D geologic model of the drilled wells under the emergency plan for Aleppo

From the linking of the sections prepared with the geologic map we note that most emergency wells are located within the Palogene carrier, specifically within the Eucene combination (lower, middle and upper) because the lower Palogene is located on depths more than 400 m, while the emergency plan wells are 250-300 m deep except some individual exceptional cases.

Also RockWorks software could draw 3D surfaces for all wells under study according to the lithological description of each one as shown in Fig (6).

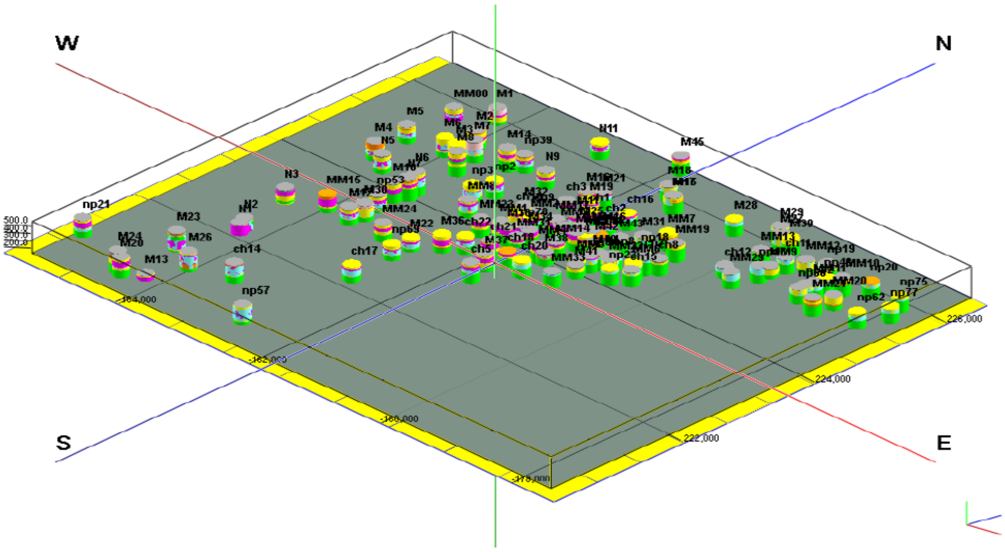


Figure.6: 3D model with the lithological description of well sections using RockWorks software

From the 3D model we deduce that most wells in the western part of the city are located on Neogene carrier, specifically in middle Meocene (Helphite) and this is clear in the general geologic plan [9] as shown in fig (7).

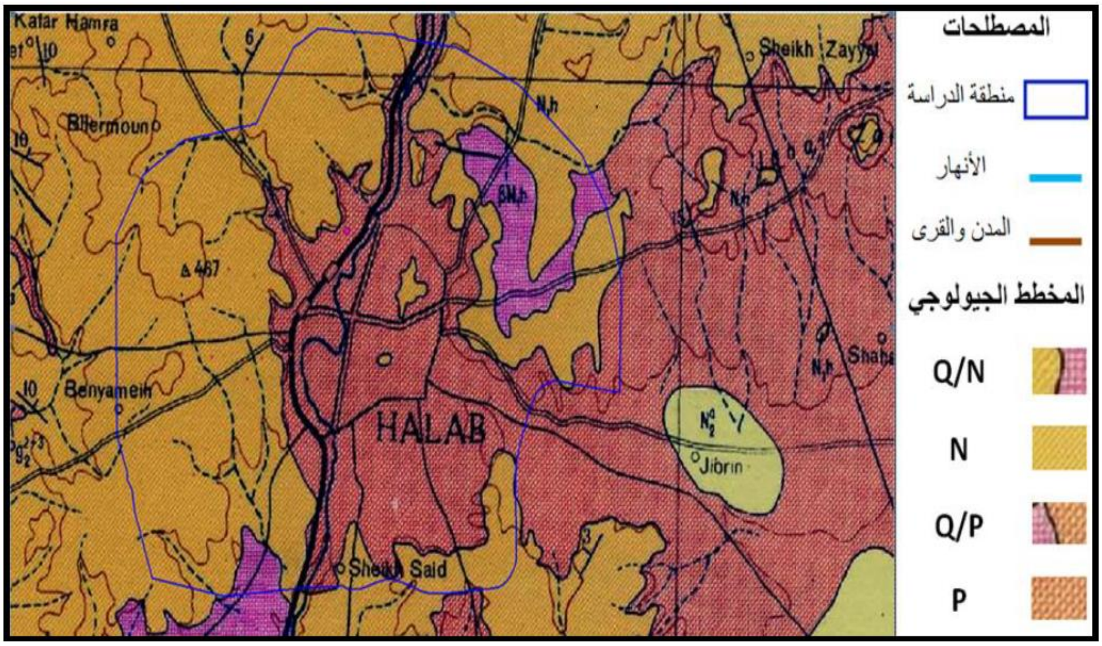


Figure.7: The general plan of the geologic structure in the area under study

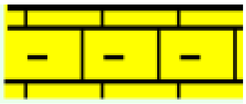
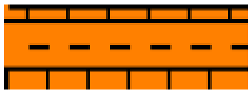
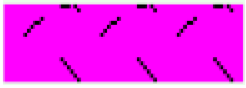
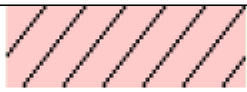
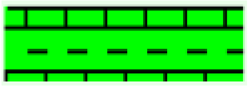
By returning back to the general geologic plan, it's shown that the Neogene aged depositions are spread in the western part of the area under study and its thickness is lower in the eastern and southeastern direction. The most important depositions are the levels of lime with basalt belonging to middle Meocene (Helphite) and Paleocene, while the water carrier is of Paleogene age which extends almost the entire studied area and its thickness increased whenever we head north and east.

The data input in this software are: the lithological and hydrological data for 239 wells and the measurements of groundwater level / table for 70 water point (well). We have also data of the pumping tests for 224 wells where the well depths, diameters and static and dynamic water levels of water, depths of the water carriers, the pumping out flows m depths of pump installation and their capacity power and the dates of performance of the 1st and 2nd pumping tests.

It is worth mentioning that based on the study of the hydrographic aquifer of Aleppo [4] we sorted each group with the same geologic structure and classified them at the same lithological description to be input into RockWorks software and they were given special codes in such a way that each group has the same color and stratigraphic code " table (1)" [1.2].

Table.1: The various geologic types of the area under study

Stratum No.	Stratum description	Geologic age	Geologic structure	Stratigraphic symbol
1	Fluvial depositions and soil	Quaternary	Agricultural soil, clay alluvia, soil, soil with stones and gravel	
			Hard lime stone, shell lime stone, sand lime stone, massive lime stone, carrier lime stone, chalk-like lime stone, chalky	

2	Lime stone, conglomerate	Helphite	lime stone, chalk, clay chalk, cracked chalk, lime conglomerate with clay mortar, carbonate mortar lute conglomerate	
3	Clay, clay lime stone	Neogene	Red colored solidified clay, carbonate clay (basalt alluvium), sandy clay, heavy basalt clay, ash clay, water saturate clay lime stone, yellow clay lime stone	
4	Basalt	Helphite	Basalt, contact area of up to clay decomposed basalt, clay basalt contact, basalt casts with lime inclusions. green basalt, black basalt, volcanic alluvium, basalt alluvium, hard basalt, basalt with lime alterations, decomposed basalt, varied basalt, basalt with lime nodes, variable color basalt	
5	Nemolite lime stone	Paleogene	White colored Nemolite lime stone, Nemolite lime stone	
6	Marl	Neogene , Paleogene	Marl, alternate light to dark mark, alternate oily marl, Calconite marl, alternately colored marl, clay marl, alternates of carbonate marl, dolomite marl, dark grey marl, marl with sand inclusions	

Preparing 3D model for the groundwater aquifer using RockWorks software, We drew the 3D hydrological model of the groundwater aquifer within the city [17] as shown in fig (8).

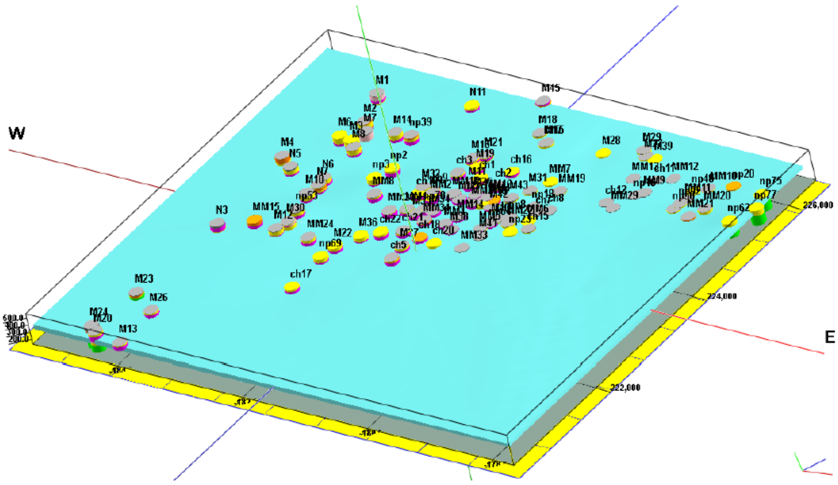


Figure.8: A 3D model for the aquifer within the city

The water levels were connected linked in wells and not for the water carriers because some wells were supplied by more than one carrier which makes difficult the identification and separation the place of the end of Neogene carrier and the start of Paleogene precisely [17], as shown in fig (9).

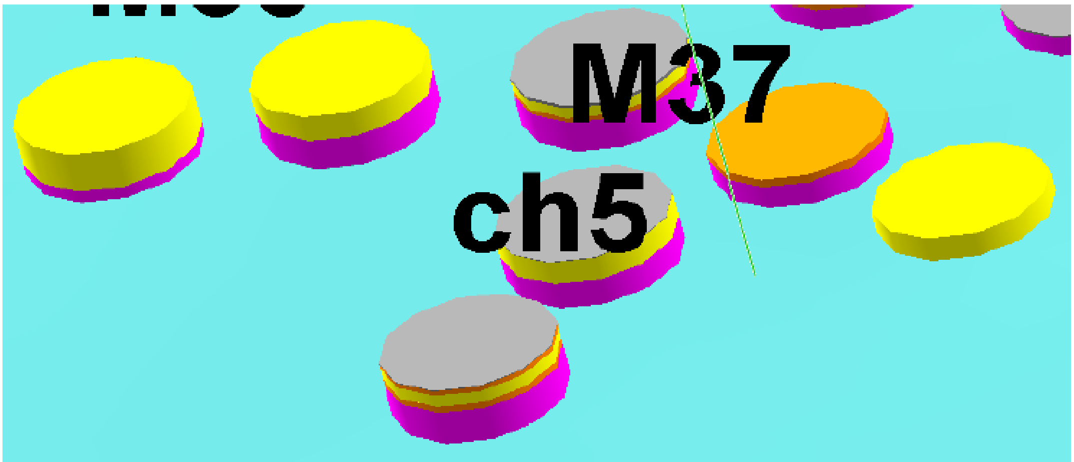


Figure.9: A magnified part of the 3D model for the aquifer within the city

We note form the figure that water in most wells appear in the basalt stratum (in violet) and this confirms that wells located within the Neogene carrier have water belongs to Helphite while wells located within the Paleogene, their water appears within the lime stone (yellow color) and also we note that some wells are fed from more than one hydrological structure.

6.4. Well or group of wells effect radius:

When we depart from the well by a distance R which is called effect radius, (Sichardt) gave the following experimental formula to estimate the value of R:

$$R \approx 3000(H - h_o)\sqrt{K} \ldots\ldots\ldots\ldots (1)$$

Where:
H: thickness of the layer contributing in flow at the end of the effect zone, m
h_0; height of water in the well, m
K: soil permeability coefficient, m/sec

Relying on the pumping test for each well and substituting in the equation which gives the runoff value of a well which penetrates the entire unconfined thickness of the aquifer which is supported by horizontal non permeable base which is in stable condition

$$Q = \frac{\pi . K\left(H^2 - h_o^{\ 2}\right)}{Ln\,\frac{R}{r_o}} \text{.........} \text{.....}(2)$$

where:

R: effective radius, r_o: well radius
From the pumping test reports of the wells under study we adopted the following:
S = H –h_o, settlement as a result of out-pumping
Q: m^3 / h

By substitution in formulae (1), (2) we obtained a logarithmic curve equation and it was solved experimentally to obtain R & K.

We drew the effective radius for all studied wells and it was shown that there were effect interfered wells in several areas of the city, as shown in fig (10).

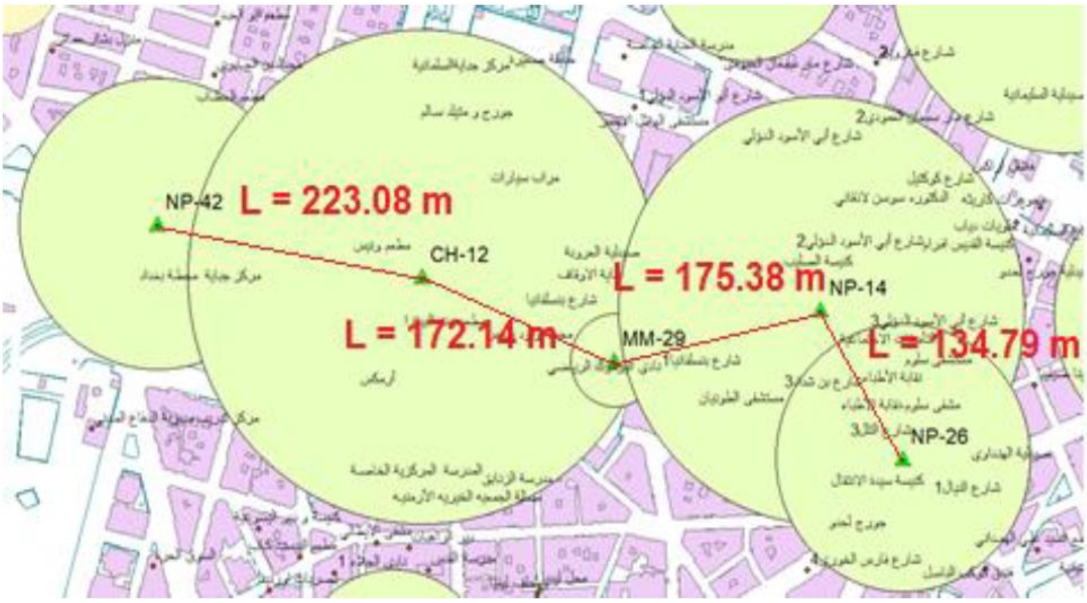


Figure.10: The locations of interfered wells in Alsolaymanieh area

To learn about the hydrodynamics of the water carriers in the studied area under the condition of pumping out from wells we prepared a databank about the interfered wells including various available information about periodic monitoring works for water levels in wells to use them in the schematic representation of the periodic monitoring data. Figures (11) & (12) show hydrographs of the monthly groundwater levels of the studied wells in that area. 11

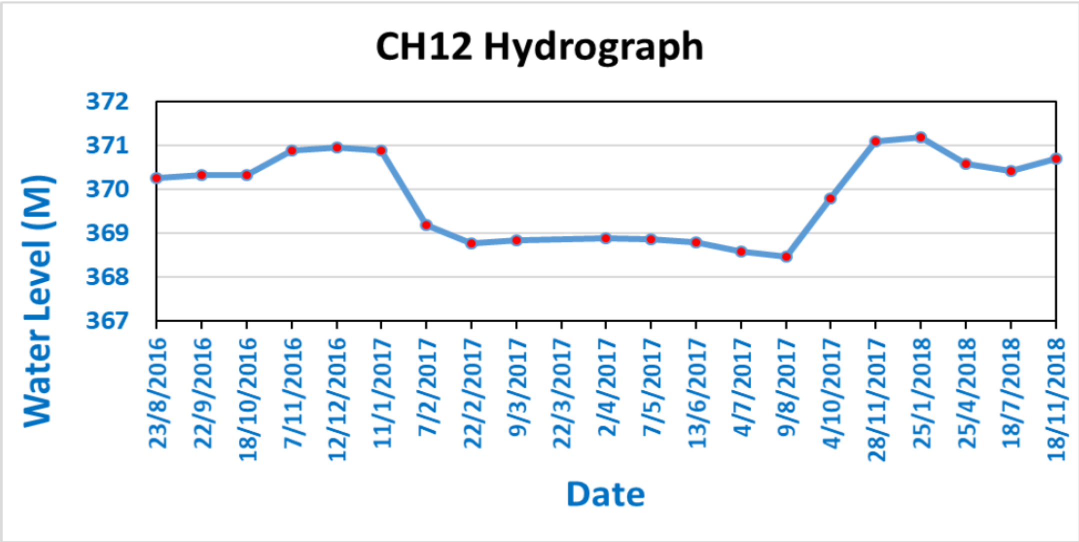


Figure.11: Well Ch12 located in Alsolymanieh area opposite to Shams petrol station

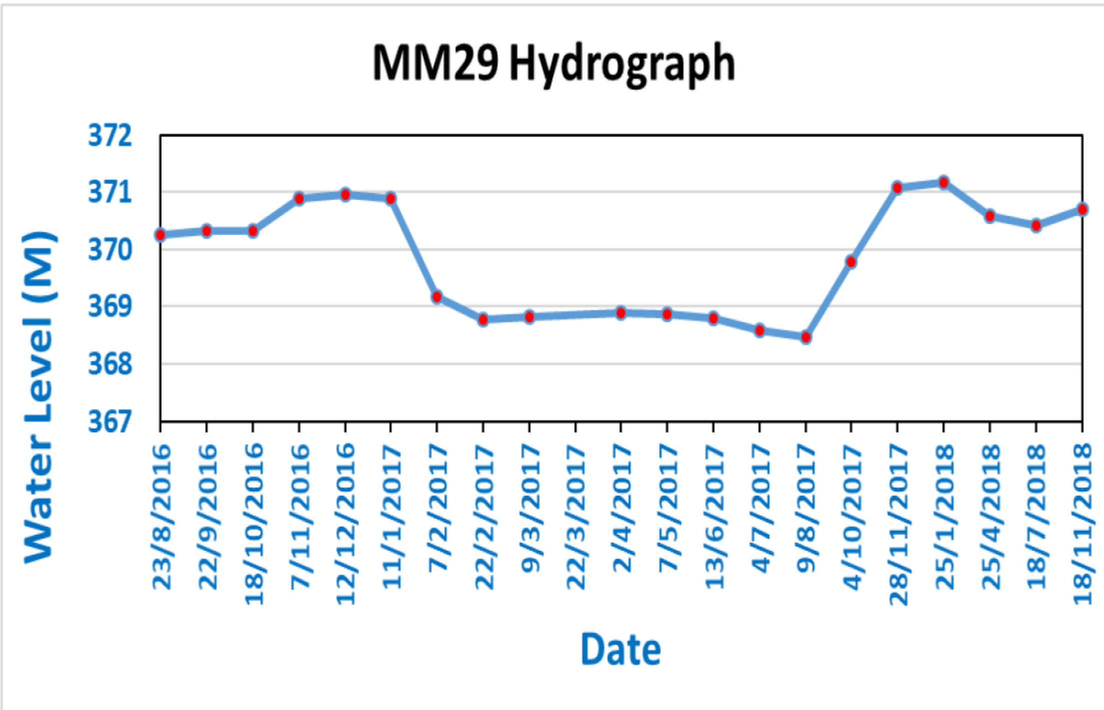


Figure.12: Well MM 29 located in Alsolymanieh area Pennsylvania street - Alyarmok club

We below give the hydrographs of the groundwater levels of some effect - interfered wells which was prepared using Excel [17], so we did the same work, where individually distributed well locations were selected within the city and this is shown by figures (13,14,15,16,17).

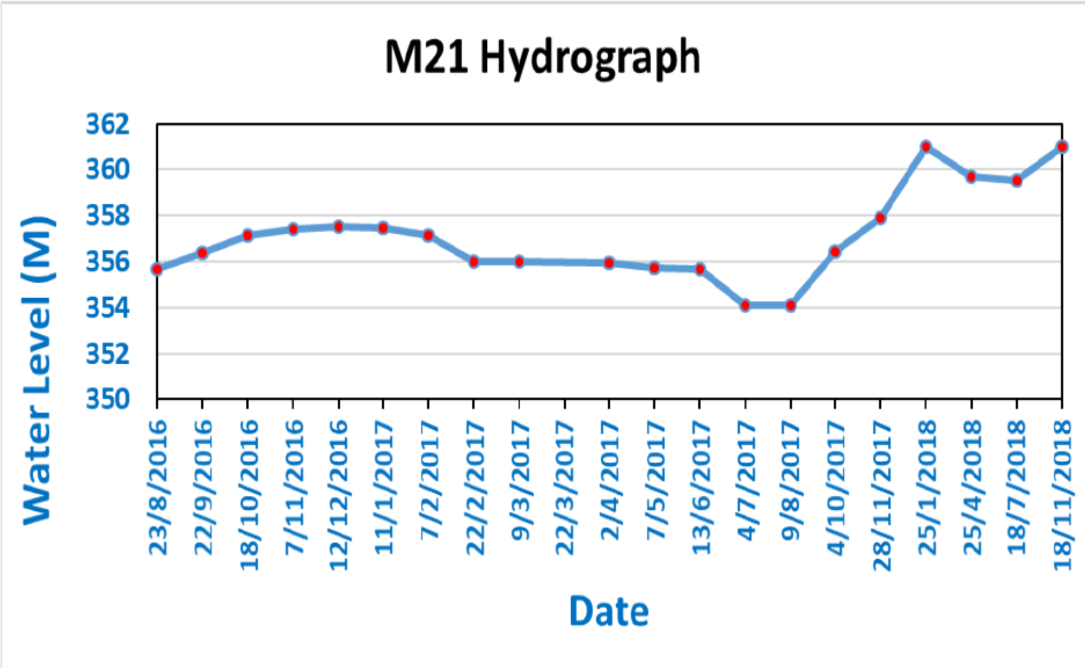


Figure.13: Well M21 located within a park north of Alshaba roundabout

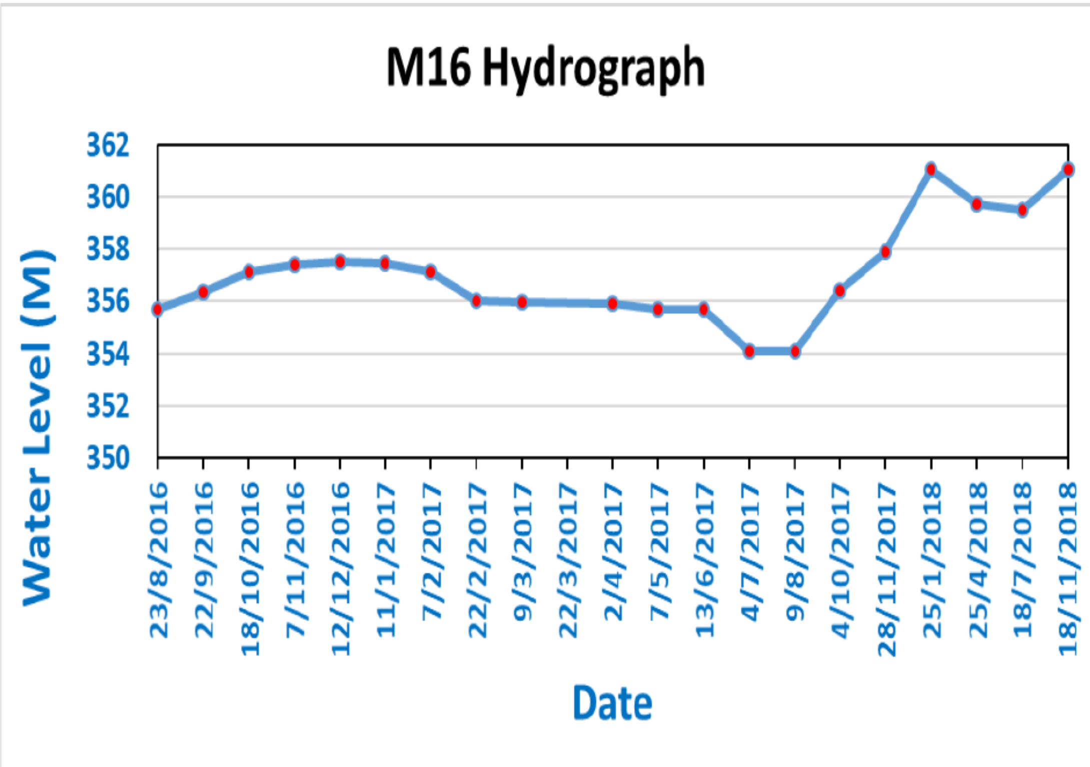


Figure.14: Well M16 located in Pullman roundabout

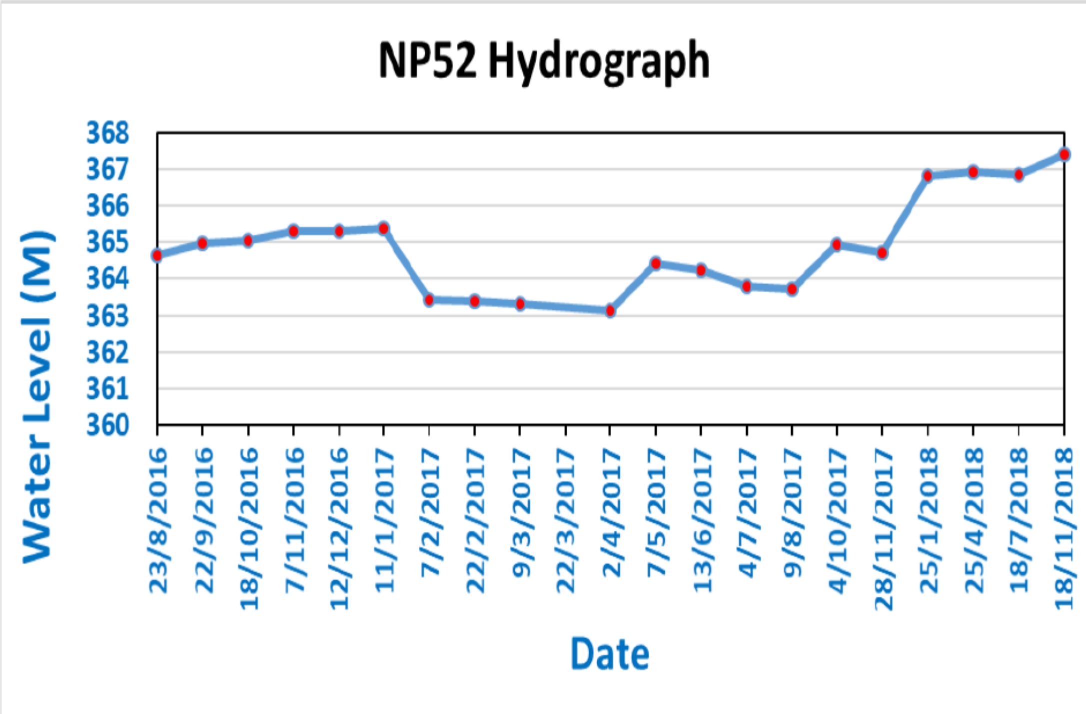


Figure.15: Well NP 52 located in Almohafaza – back to Franciscan

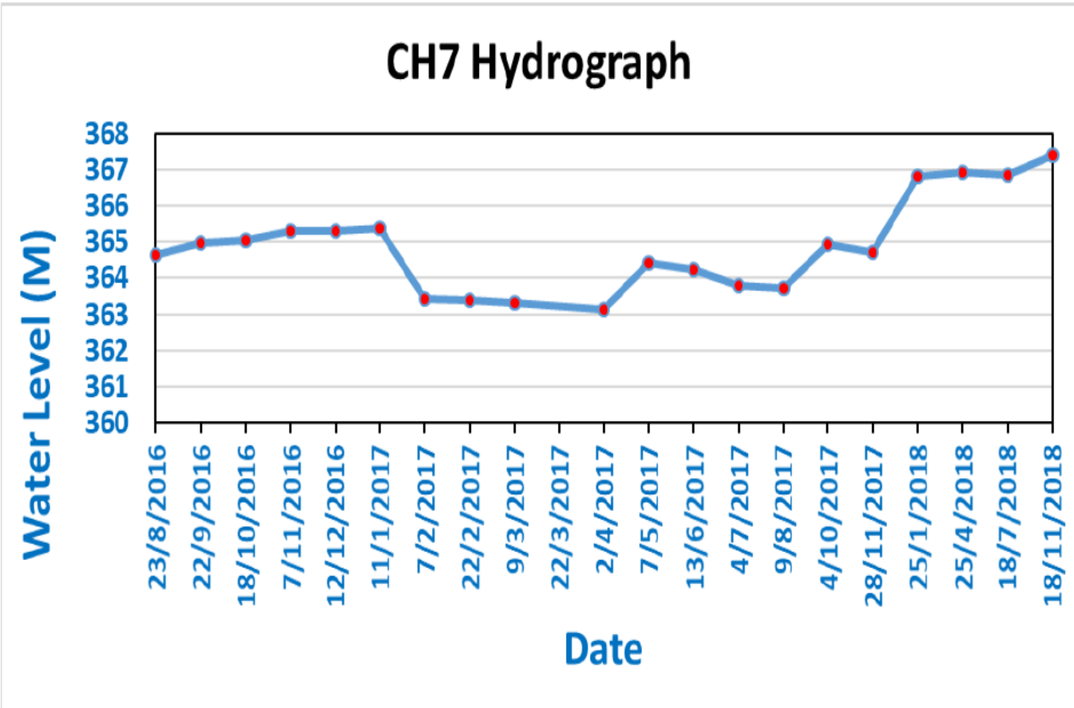


Figure.16: Well Ch7 located opposite to the directorate of education

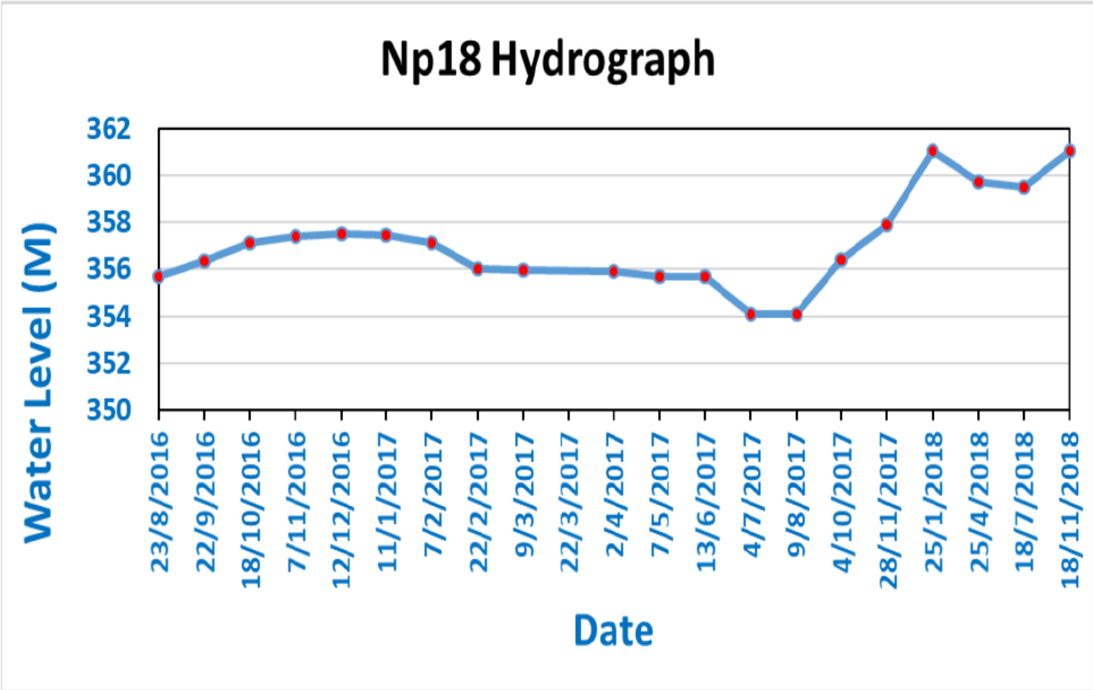


Figure.17: Well NP18 located in Almohafza – Souk Alintag area

Through the above figures we note that when the wells` effects are interfered in certain area, the piezometric line of these wells will be very similar and almost identical, and they will have the same behavior as if these wells were operating as a single well which indicates the homogeneity in hydraulic characteristics of the carrier and gave the same behavior of these wells, so when these closely located wells are operated (as the case in Aleppo) the depression cones of these wells will superimpose and interfere with each other which affects the common depression and drainage cone simultaneously. Also we found in most of these wells a lowering of the depression cone as a result of extreme pumping and we focus specifically on the period when the terrorist Daesh (ISIS) group cut the water supply completely to Alkhafsa pumping station which supplies water to Aleppo for a period exceeding 77 days.

It was noted in the period from 22.01.2017 until 24.04.2017 which is about 77 days that the reduction in water levels of most wells because of the excessive pumping out as a result of complete water outage from the main source (Alkhafsa) and because also of power outage at that time.

6.5. Using geographic information system (GIS) and the schematic representation systems:

The hydrological database was linked with the geographic information system ArcGIS and the schematic representation systems RockWorks along with Excel. Through this system we drew the equal lines of groundwater levels for identifying the general nature of the water flow before the pumping out. Also we drew the maximum and minimum equal lines of groundwater levels in case of excessive pumping on 09.03.2017 and the case of full cone after the pumping is stopped on 07.05.2017

For exploring and monitoring the fluctuations of the water cushion during pumping operations we adopted the principle of color coding as an indicator for the variation of the groundwater levels within the study as function to the pumping out “ table (2)”.

Table.2: Indicator of variation of groundwater as a function to pumping out

Color									
Water level line	350	355	360	365	370	375	380	385	390

This what we will clarify by figures (18,19,20,21,22) by the help of references [17,18]:

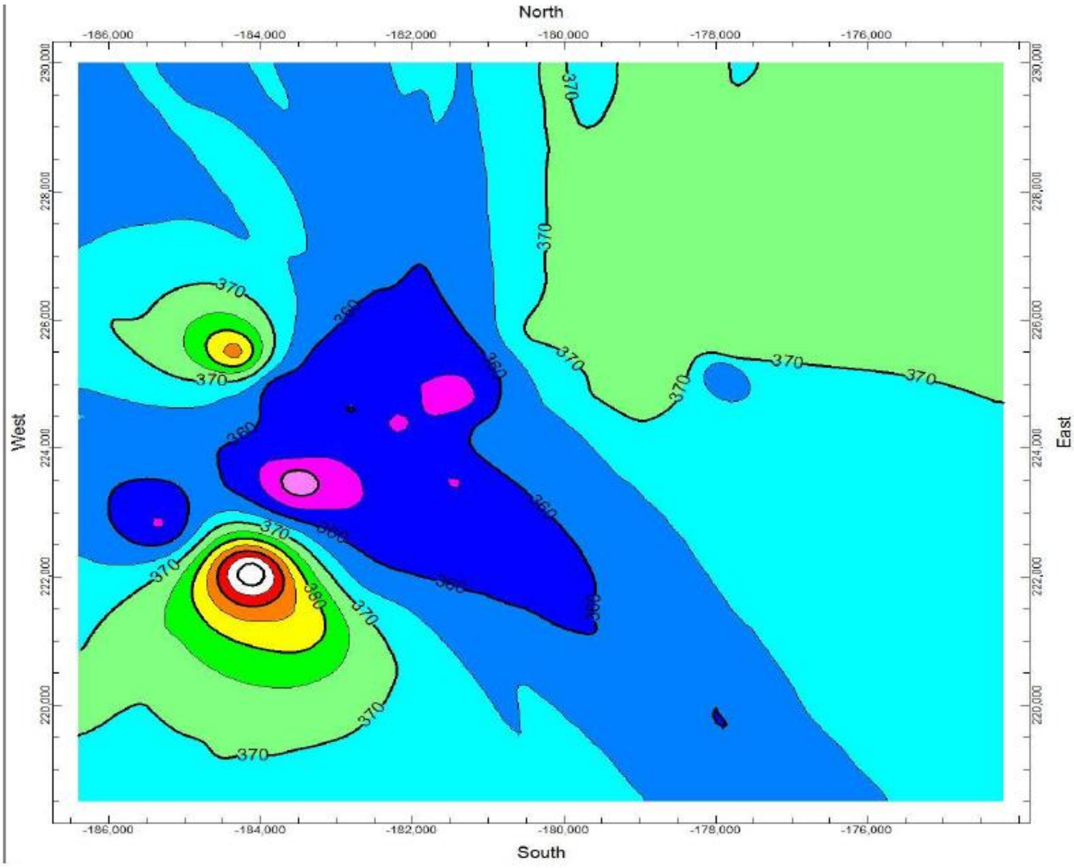


Figure.18: Line of equal groundwater tables on 11.01.2017

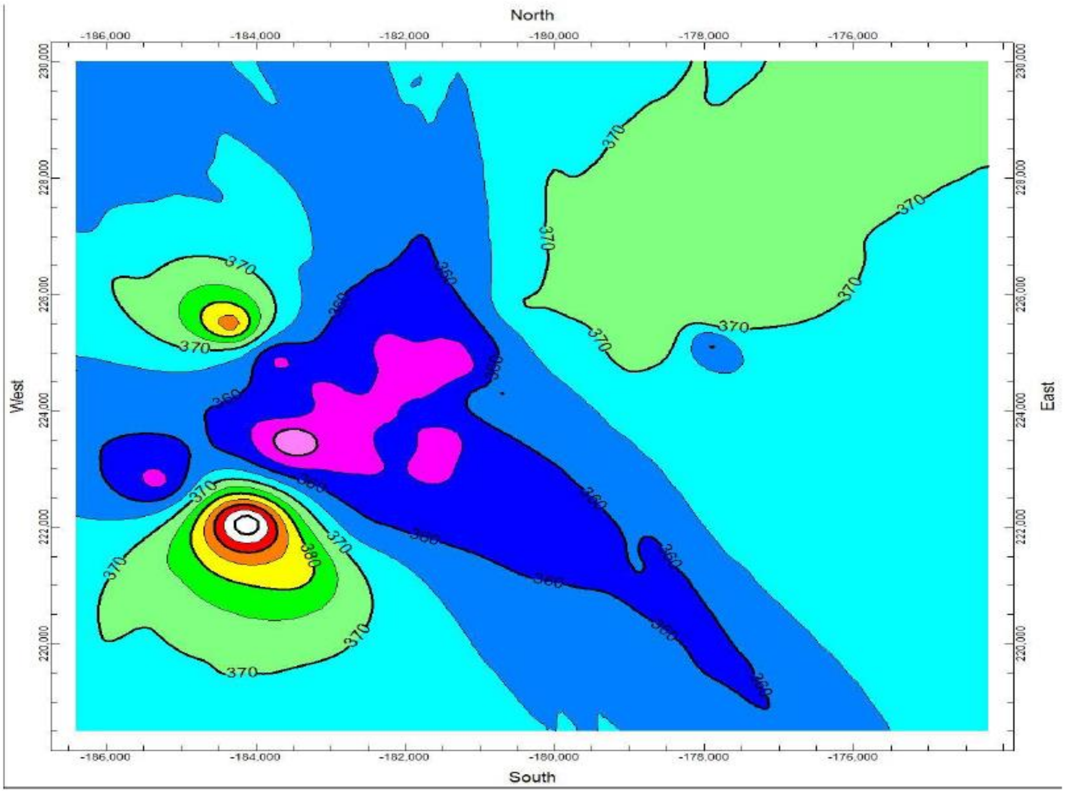


Figure.19: Line of equal groundwater tables on 07.02.2017

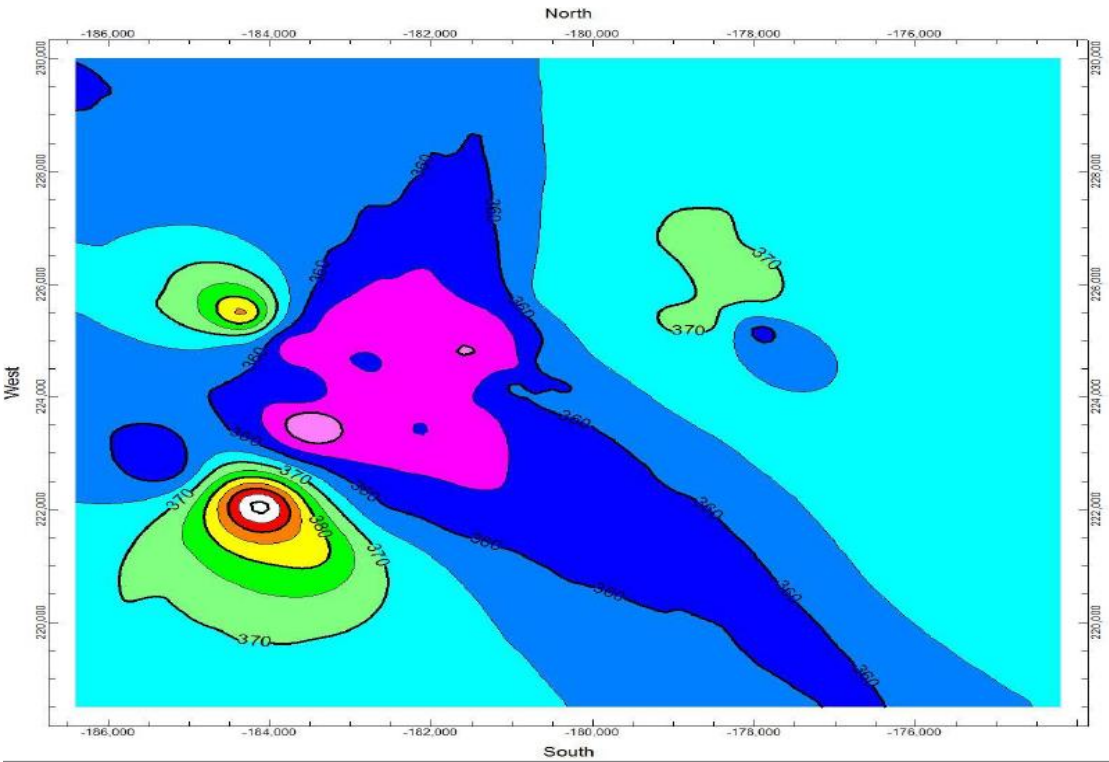


Figure.20: Line of equal groundwater tables on 02.04.2017

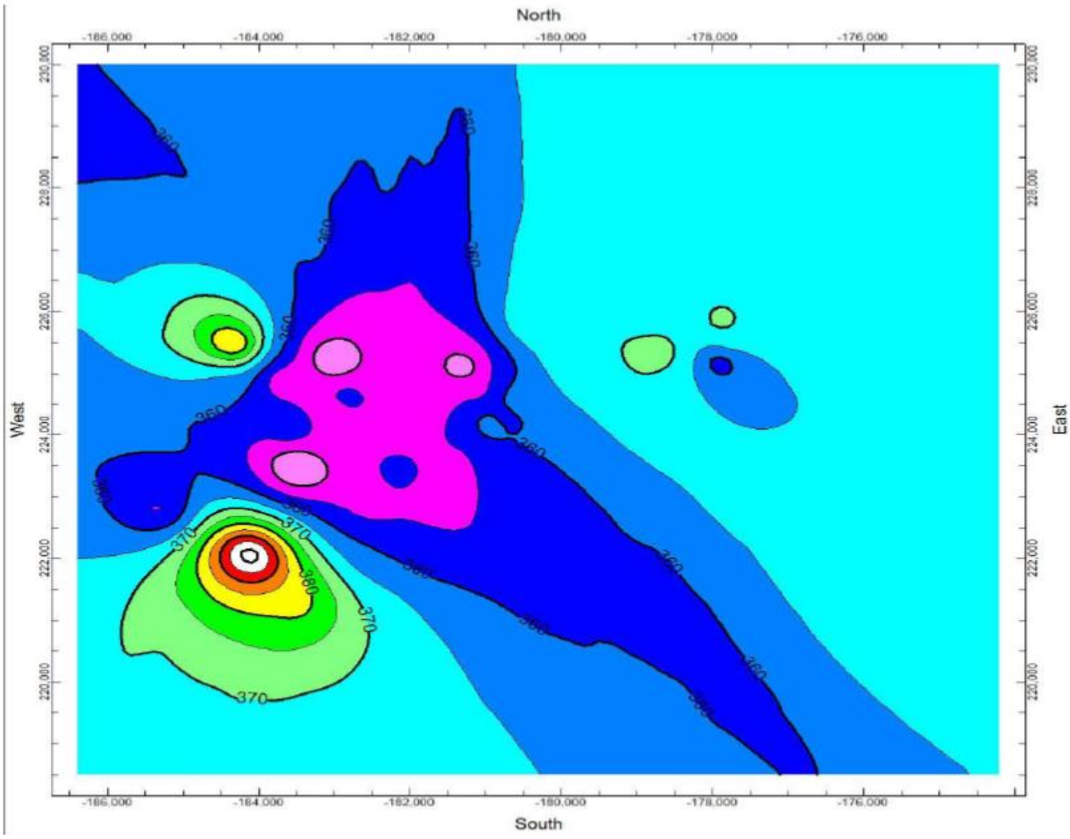


Figure.21: Line of equal groundwater tables on 04.07.2017

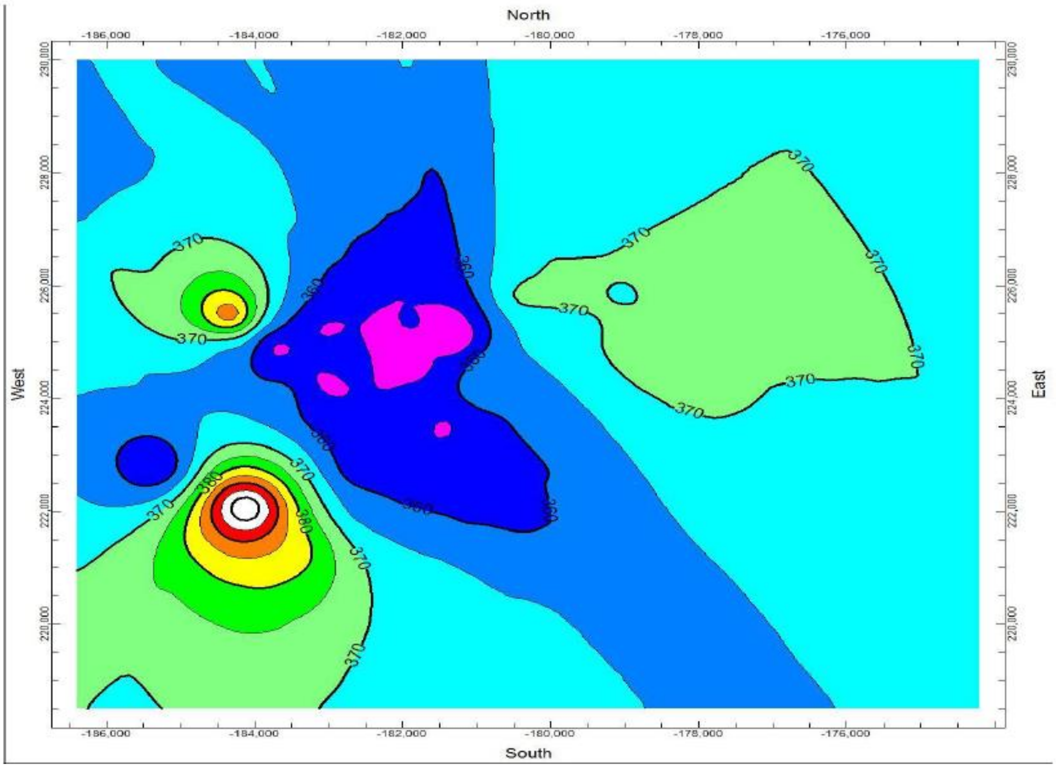


Figure.22: Line of equal groundwater tables on 04.10.2017

Through the screening of the water cushion variation as a result of pumping operation we were able to know the water surface dynamics movement where it's clear that water cushion was highly changing in the low area of the city center, while the wells located in western parts of the city maintained higher levels even in intensive pumping where it's clear from figure (18) which represents the line of equal groundwater levels in Aleppo on 11.01.2017 and that the surface area under the groundwater equal lines below the level of 360 m was largely less than the later dates where the surface area starts to increase remarkably during the intensive pumping as shown in figures (18,19) and the reduction of groundwater levels reached its maximum on 04.07.2017 as shown in figure (21) and with return of water supply to the city and being pumped intermittently , this surface area starts to decrease on 04.10.2017 as shown in figure (22). From the above it's clear that there is a reduction in the groundwater levels in groundwater carriers from their normal condition within the city in spite of stop of pumping or non operation of wells at their full capacity.

We will, in the future, prepare a mathematical model which allow the linking of the well flows with the levels of the first and second groundwater carrier and the future forecasts about groundwater using the typical hydrogeological model including the specification of the boundary conditions of the studied area and the geometrical dimensions of the water carrier under study and its hydraulic characteristics to know the possible variations occurring to it as a result of current water investments and the future prediction on the light of the investment.

From here we will try to set a future regime for the investment of the groundwater within the city.

7. Conclusions

1) The lithological sections demonstrate that there are some wells which contain more than one water carrier and the reason for that is that the area belongs to more than hydrological formation.
2) We noted from the hydrological model that the water yield of the wells located in low area (city center) belong to Paleogene carrier while in the wells of the western and areas (such as Alizaa and Alhamadanieh) they belong to Neogene carrier.
3) It was shown from the wells locations and allocating them specific coordinates and linking them with the organizational map of Aleppo, that most wells drilled under the emergency plan were close of each other and are interfered which affects both the common depression cone and draining as if these wells are operating as one well which indicates a homogeneity in hydraulic characteristics of this carrier which gave the same behavior.
4) All maps of equal groundwater levels show that there still a reduction in the groundwater level in groundwater carriers within the city in spite of returned regular water supply to the city from Euphrates river and the operation of few wells only.

8. Recommendations and suggestions

1- We confirm the necessity of continual taking of monthly periodic readings of the groundwater levels for as long as possible which enable the determination of the underground aquifer behavior beneath Aleppo with the return of regular water supply to the city and stop of pumping from the studied wells.
2- The deepening of drill height for some wells in practically infeasible because in spite of existing wells with two carriers, however there is an impervious layer is separating them which makes the water yield of the water carrying layers relatively weak and therefore these wells were working as a collection tank.

3- The increased groundwater levels in some wells is not necessarily because of stop of pumping from the investment wells or non-drilling of new wells. This can help the groundwater aquifer to replace and compensate part of its losses during last years, but also it can be because of the seepage of rainwater. We will in the next stages of this study to try to know if there is a clear effect of rainwater on the groundwater aquifer supply / feeding in the area under study.

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