Introducing The Index Of Confined Aquifer Heterogenity

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Abstract-This research studies the interaction between the groundwater and formation non heterogeneity, the research was conducted in the three areas ofDarb El Arbeain, southern western Desert, Egypt. Darb El-Arbeain area related to the Red sea and East Oweinate district, where the main factors controlling the structural framework in the area are (EGSMA, 1987); Tensional stresses led to a great number of faults of different trends and types, Vertical and diagonal uplifting of the basement rocks, and Three anticlines with gentle angles of.Through different pumping scenarios for each case study, by running each case for 110 %, 180%, 280%, and 370% of initial calculated recharge, the study revealed that the heterogeneity of the aquifer depends on both the time required for water level equilibrium under dynamic condition and the percentage of difference between max and min value of drawdown.

INTRODUCTION

Darb El-Arbeain projects aims for reclamation of 12, 000 feddans in the western Desert of Egypt.Darb El-Arbeain area lies between long. 29^{o} 00/ and 31^{o} 00/ E and lat. 22^{o} 00/ and 24^{o} 30/ N (Fig. 1). Geographically It is divided according into three areas: Northern part (case one), middle part (case two) and Southern part (case three). The target of this study is to introduce the formation instability (inhomogeneous degree) effects on groundwater exploitation in confined aquifers, the effect on aquifer equilibrium time and the value of drawdown.

AREAS OF STUDY

Darb El-Arbaein is subdivided into three geomorphologic units, the southern Naklai-Shebpene-plain; the western Atmur peneplain; and a plateau surface. The litho-stratigraphic successions are divided into seven units, from base to top: 1) Precambrian basement 2) Paleozoic-Mesozoicsandstone; 3) Lower Cretaceous; 4) Upper Cretaceous; 5)Paleocene; 6) Eocene; and 7) Quaternary. Darb El-Arbaein area is related structurally to the Red Sea and south western regions. The faults have identified in E-W, NE-SW and NW-SE and three anticlines (BirKiseiba, Rage, and Shirshir). The stored water in Nubian sandstone is mainly fossilized water and ranges from20000 to 40000 y.

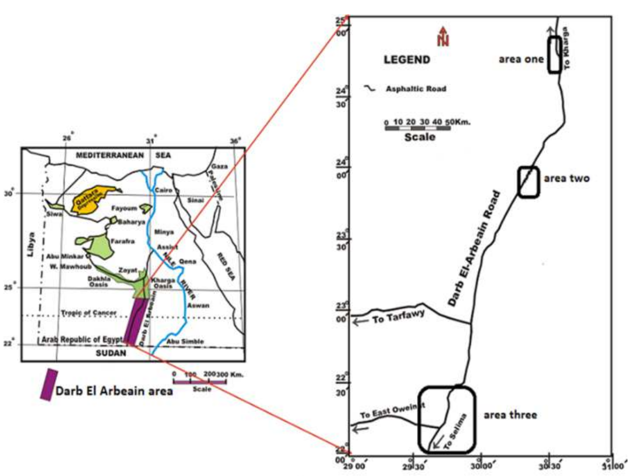

Fig.1: Darb El Arbeain Map

The case no 1 extends 90 km to the south from Paris town and has an area of 90 km^2. Meanwhile the second case extends for 80 km to the south of the northern part and has 120 km^2 in area. The third case extends for 200 km to the south of the central part and has 170 km^{2}in area.

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Article History: Received: July 02, 2019, Accepted: Sep 28, 2019

2.1. First Case study (northern area of Darb ElArbeain)

Hydraulic conductivity; Kx = Ky = 3.07 m/day Kz = 0.307 m/day, no of aquifers; 1 (divided into 4 layers), no of rows = 100, no of columns = 183 (each cell is 60*60 mt), Average Specific storativity = .0001 m^{-1}, Average total porosity = 0.3, average effective porosity = 0.15 (El-Beih, 2007), groundwater level at 2004 taken from Kamel et al. 2004 (Fig.2), currently average pumping rates of the wells is 1700 m^3/ day. Piezometric heads Bounding the area (Fig.3);the western boundary; consist 2 segments, line a-b represent constant head 73 m, mean while line from b-c represents 88 m.the eastern boundary; line d-e represent constant head 58 m, and line e-f represent Constant head 70 m. the northern and southern parts represent no flow boundary. Area one target is to reclaim around 3 000 feddans. Calibration (Fig.4) involved comparison of the model results and observed heads at 22observation points (taken from pumping wells) from a piezometric head map to run in a steady state simulation, visual mod flow calibration is 94 %. once the model calibrated, the calculated hydraulic heads were used as initial heads for the transient flow scenarios.

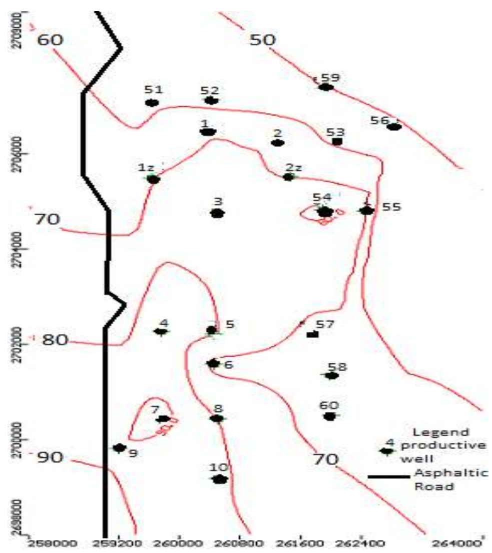

Fig.2: Piezometric levels in area one, Darb El Arbeain

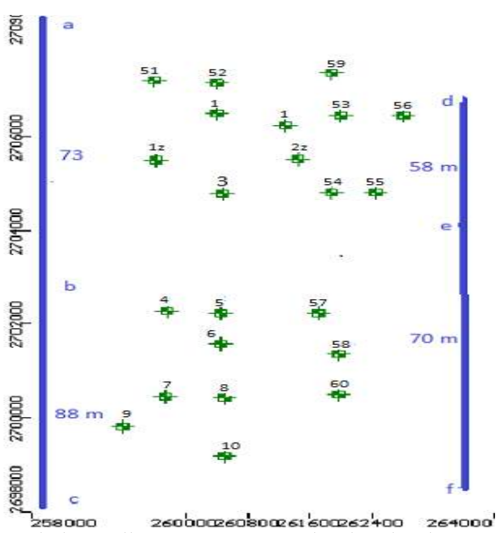

Fig.3: Piezometric heads bounding area one, Darb El Arbeain, m, used for calibration

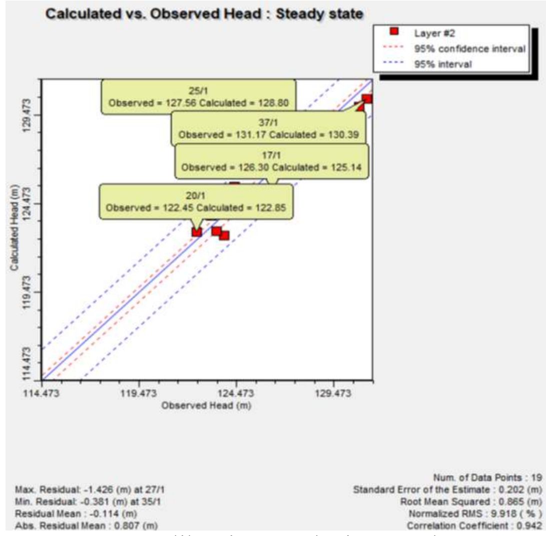

Fig.4: Calibration results in area three

2.2. Second Case study (Middle area of Darb ElArbeain)

Applying modelling and correlate with field data (visual mod flow calibration which is 94 %).

The hydraulic conductivity; Kx = Ky = 2.1 m/day Kz = 0.21 m/day, no of aquifers; 1 (divided into 4 layers), no of rows = 250, no of columns = 190 (each cell is 50*50 mt), Average Specific storativity = .0001 m^{-1}, Average total porosity = 0.3, average effective porosity = 0.15 (El-Beih, 2007), Piezometric level; taken from Korany et al. 2002 (Fig.5), currently average pumping rate of the 27 wells is around 2000 m^3/ day. Piezometric heads Bounding the area used for calibration (Fig.6); the western boundary; consist 2 segments, line a-b represent constant head 135 mt, meanwhile line from b-c represents 131 mt. The eastern boundary; line g-h represent constant head 123 mt, line h-i represent Constant head 119 mt, and line i-j represent Constant head 117 mt. The northern boundary; line d-e represent constant head 125 mt, line e-f represent Constant head 129 mt. The southern parts represent no flow boundary. Area two target is to reclaim around 4 000 feddans. Calibration (Fig.7) involved comparison of the model results and observed heads at 24. observation points (taken from pumping wells) from a piezometric head map to run in a steady state simulation, once the model calibrated, the calculated hydraulic heads were used as initial heads for the transient flow scenarios.

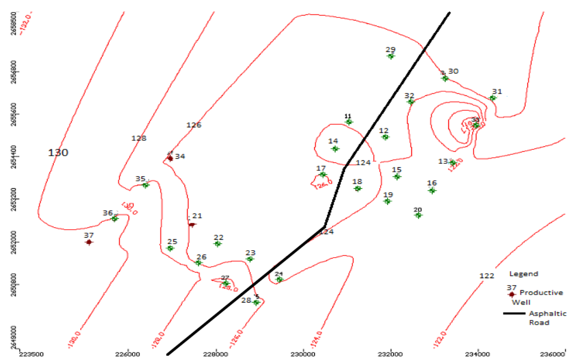

Fig.5: Piezometric levels in area two, Darb El Arbeain

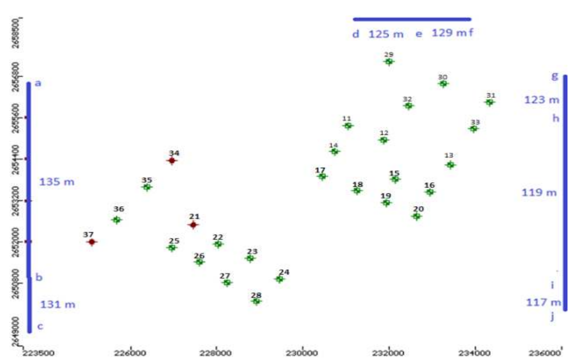

Fig.6: Piezometric heads Bounding area two in Darb El Arbeain, m, used for calibration

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Article History: Received: July 02, 2019, Accepted: Sep 28, 2019

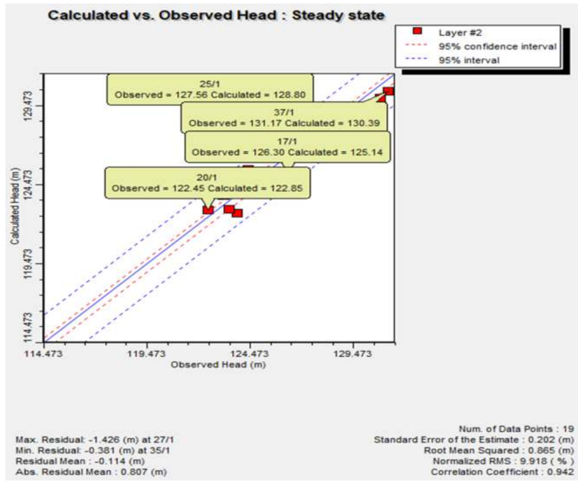

Fig.7: Calibration result to area two, Darb El Arbeain

2.3. Third Case Study Three (Southern Area of Darb ElArbeain)

The hydraulic conductivity; $K_x = K_y = 6.5$ m/day $K_z = 0.65$ m/day, no of aquifers; 1 (divided into 4 layesr), no of rows = 200, no of columns = 200 (each cell is 50*50 mt), Average Specific storativity = .0001 m^{-1}, Average total porosity = 0.3, average effective porosity = 0.15 (El-Beih, 2007), Piezometric level; taken from Korany et al. 2002, (Fig.8), currently the pumping still not yet started from the area. (have 30 wells ready). Piezometric head Bounding the area (Fig.9); the western boundary; consist 3 segments, line a-b represent constant head 205 mt, meanwhile line from b-c represents 204 mt, and line c-d represents 218 m. The eastern boundary; line e-f represent constant head 219 mt, and line f-g represent Constant head 226 mt, and line g-h represent constant head 222 m. The southern parts line d-e represent constant head 223 mt. The northern parts represent no flow boundary. Area three target is to reclaim around 5 000 feddans. Calibration (Fig 10) involved comparison of the model results and observed heads at23 observation points (from current wells) from a piezometric head map to run in a steady state simulation, calibration is 92 %, once the visual mudflow model calibrated, the calculated hydraulic heads were used as initial heads for the transient flow scenarios.

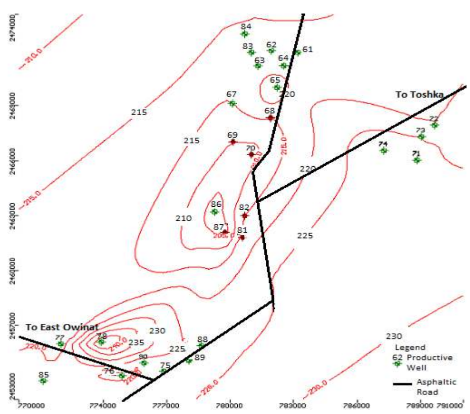

Fig. 8: Piezometriclevels in area three, Darb El Arbeain

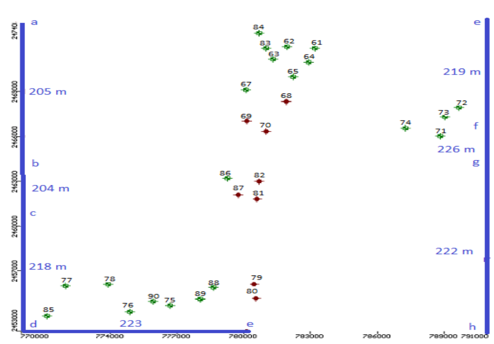

Fig.9: Piezometric heads bounding area three, Darb El Arbeain, m, used for calibration

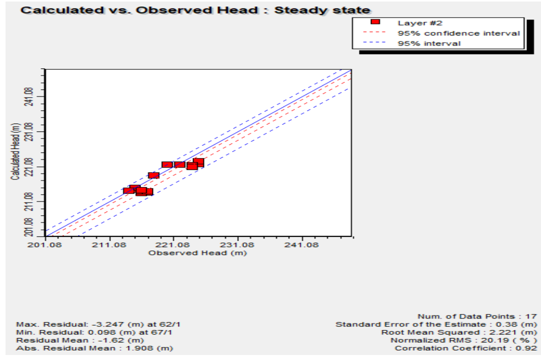

Fig. 10: Calibration results in area three

GEOLOGIC STRUCTURES IN DARB EL ARBEAIN

3.1. Geologic Structuresin Northern Area

The northern area of Darb El Arbeain is affected by 19 normal subsurface faultsrunning horizontally from one to more than four kilometers.The sediments still connected with each other horizontally through the faultsand tabulated in below table 1, and Fig 11 (Rafik, 2003);

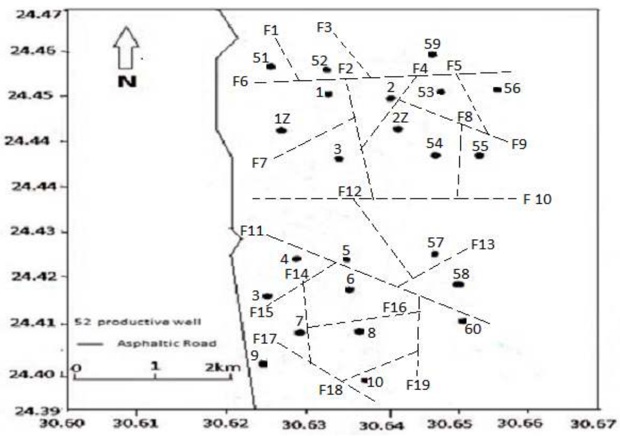

Fig.11: Locations of faults in northern area of Darb El Arbeain, Rafik, 2003

Table 1: The delineated subsurface faults for area one in Darb El Arbeain (Rafik, 2003)

Fault no	Location	Throw, m	Direction of throw
1	Between wells 51 and 52	**2**	**NE**
2	Between wells 1 &3 and wells 2 & 54	3-13-15	NE
3	Between wells 52 and 59	21	NE
4	Between well 2 and wells 53 & 54	29-2	SE
5	Between wells 53 and 56	49	SW
6	Between wells 51, 52, & 59 and wells 1, 2, 53, and 56	37-39-36-57-28-77	N
7	Between wells 1 and 3	10	NW
8	Between wells 54 and 55	29	W
9	Between wells 53 & 56 and wells 54 & 55	27-56-7	NE
10	Between wells 3, 54, & 55 and wells 5 &57	65-45-60-31	N
11	Between wells 5 & 58 and wells 4, 6, & 60	18-10-1	NE
12	Between wells 5 and 57	20	NE
13	Between wells 5 & 57 and well 58	9-29	NW
14	Between well 7 and wells 6 & 8	1-4	W
15	Between well 4 and wells 6 & 7	8-9	SE
16	Between well 6 and well 8	3	NW
17	Between well 9 and wells 7,8 & 10	11-7-13	NE
18	Between well 8 and well 10	6	NW
19	Between well 60 and wells 6, 8 & 10	28-31-25	E

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Article History: Received: July 02, 2019, Accepted: Sep 28, 2019

3.2. Geologic Structures in Middle Area

The study of geologic structures in the middle part of Darb El-Arbeain area is best illustrated by following subsurface geologic sections in Fig 12 and Fig 13. Most of these faults have the NW-SE trend. They are affecting the whole sedimentary section. These concealed normal faults are recognized as follows (Nagaty, 2003), (F; fault no):

1- **F1**; lies between well 29 and well 32. It has a throw of about 25 m. (Section, A – A/).
2- **F2**; lies between well 32 and well 12. It has a throw of about 12 -23 m. (Section, A – A/).
3- **F3**; lies between well 12 and well 18. It has a throw about 52. (Section, A – A/).
4- **F4**; lies between well 18 and well 24. It has a throw of about 23- 42 m. (Section, A – A/).
5- **F5**; lies between well 24 and well 28. It has a throw about 6– 3 mt. (Section, A – A/).
6- **F6**; lies between well 12 and well 17. It has a throw about 32- 20 m. (Section, B – B/).
7- **F7;** lies between well 17 and well 21. It has a throw about of 40 -80 m. (Section, B – B/).

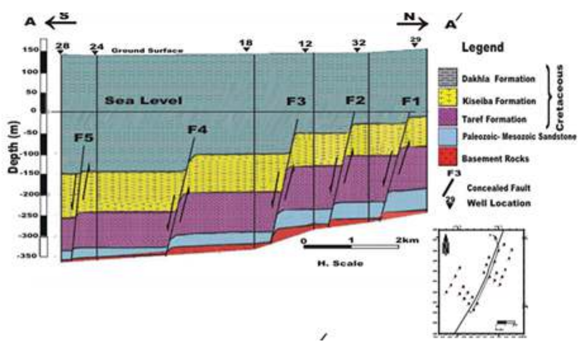


Fig.12: Subsurface geologic section A-A' in area 2, Darb El Arbeain, Nagaty, 2003

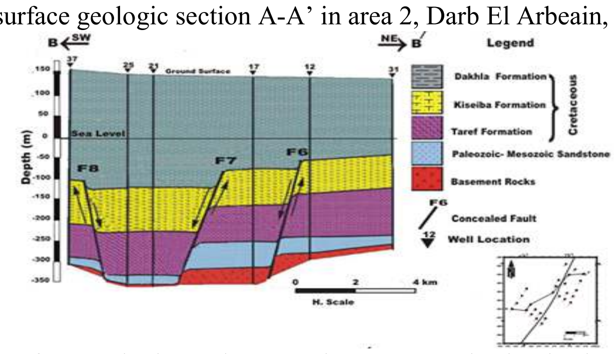


Fig.13: Subsurface geologic section B-B' in area 2, Darb El Arbeain, Nagaty, 2003

8- **F8**; lies between well 25 and well 37. It has a throw of about 50 -30 m. (Section, B – B/).
The last seventh and eighth faults forming a small graben at the area surrounding both
Sites of wells 25 and 21. (Section, B – B/).

3.3. Geologic Structures inSouthern Area

A total number of twenty-one faults affecting on area three, revealed by Rafik, 2003 (table 2, and Fig 14), where;the basement changing rapidly in the northern direction of the area leading to the decrease of thickness in water bearing units from the southern to the northern direction, and bringing a direct contact between permeable bearing units (sandstone), partly with the semi-permeable clay units, leading to a decrease in the transmissivity and hydraulic conductivity values, and increase the hydraulic gradient due north and north west directions.

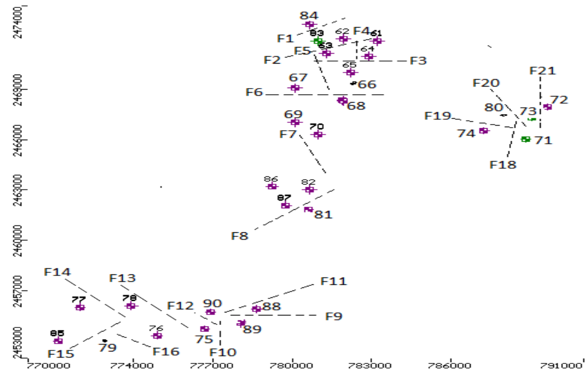


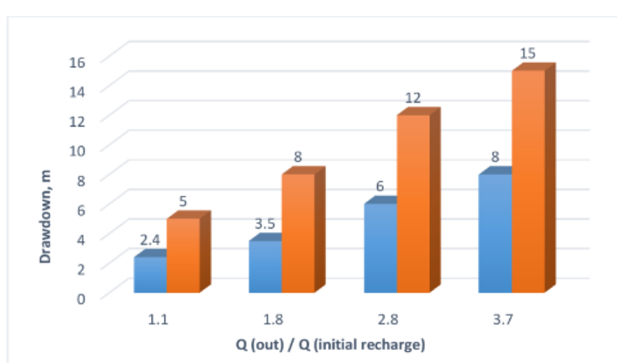
Fig. 14: Locations of faults in southern area of Darb El Arbeain, Rafik, 2003

Table 2: The subsurface faults for area three of Darb El Arbeain (Rafik, 2003)

Fault no	Location	Throw, m	Direction of throw
1	Between well 84 and wells 62 &83	12-9	W-E
2	Between wells 62-83 and wells 61& 63& 64	60-73	W-E
3	Between wells 63- 64 and well 65	27-16	W-E
4	Between wells64-61 and well 63	12-9	N-S
5	Between wells 65 & 83 and wells 66& 67	32	N
6	Between wells66 & 67 and wells 68& 69 & 70	16-22	E-W
7	Between well 70 and wells82 & 86 & 87	40	S
8	Between wells 70-82-86-87 and well 81	25	N
9	Between well 88 and well 89	22	E
10	Between well 89 and well 75	36	W
11	Between well 88 and well 90	4	W
12	Between well 75 and well 90	36	E
13	Between well 90 and well 76 & 78	6-15	E-W
14	Between well 77 and well 78	11	W
15	Between wells 77- 85 and well 79	10	E
16	Between well 76 and well 79	20	W
17	Between groups of wells along Tusky road and the western wells	10 to 37	W
18	Between well 71 and well 74&80	12	N
19	Between well 74 and wells 80& 73 & 72	5	W
20	Between wells 72-73 and wells 74&80	44	W
21	Between well 72 and wells73 & 80 & 74	36	N

Equilibrium In Darb El Arbeain Confined Aquifers Under Dynamic Conditions

The drawdown response in all areas under different pumping rates are illustrated in Fig. 15, 16, 17, and 18. Area two and area three showing that maximum Drawdown is more than three times the minimum drawdown and more time for stability representing more inhomogeneity. Meanwhile area one representing more stability of the confined aquifer, more smoothly changing in the aquifer properties and more proper distributing of the wells reducing the individual effect of the wells on each other due to relatively less time for equilibrium and the difference between maximum and minimum Drawdown is in the range of twice.



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Article History: Received: July 02, 2019, Accepted: Sep 28, 2019

Fig. 15: Min. Vs Max. Drawdown, m, in area one under different pumping rates

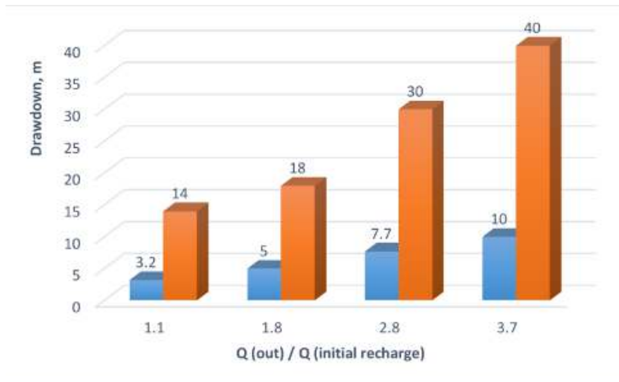

Fig.16: Min. Vs Max. Drawdown, m, in area two under different pumping rates

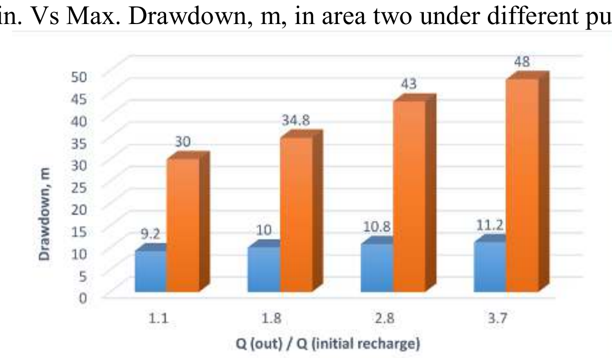

Fig. 17 : Min. Vs Max. Drawdown, m, in area three under different pumping rates

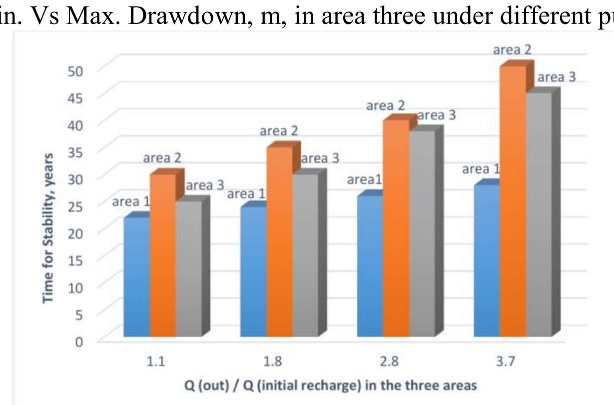

Fig.18: Time for stability under different pumping rates in the three areas

RESULTS AND DISCUSSION OF THE AQUIFER FORMATION STABILITY INDEX

The index of aquifer formation stability is indicated through;

a- The time required for water level equilibrium under dynamic or pumping conditions, which sometimes may be also used to clear poor hydraulic properties of the aquifer, but here we will use it for confined aquifers with good potentiality. In first case the time required for equilibrium in dynamic condition while pumping out from the aquifer 370 % of the initial recharge is around 28 years, comparing same pumping conditions with area two and area three; the time required for water level equilibrium are 45 years and more. This reflects more stability in northern area compared with second and third areas, but still affected by some aquifer formation instability due to tectonic movements (Fig. 19). So more aquifer formation stability expresses less time than 28 years required to reach water level equilibrium while pumping out from the aquifer 370 % of the initial recharge to the aquifer.

b. The percentage of difference between max and min value of drawdown in the aquifer. Which also may be used for expressing low hydraulic properties but here will be dedicated for good confined aquifer potentiality. In the first case the max value of drawdown is around 2 times of minimum drawdown value which confirm more stability comparing with second and third case studies (Fig. 19). Second and third cases shows that max drawdown values are more than 3 times of minimum value of drawdown. So more aquifer formation stability expressthat the max value of drawdown is less than 2 times of the min value of Drawdown.

c.

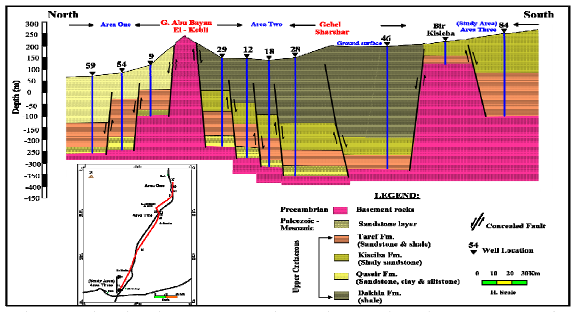

Fig.19:A much generalized hydrogeological cross section along the three areasof Darb El Arbaein, International Journal of Geosciences, 2012

CONCLUSIONS

The study areaslocated as southern western desert of Egypt. It is characterized by arid climatic conditions. Four different pumping scenarios were applied for 25, 50, and 100 years. Through applying visual modflow and correlation with field data. The results indicated that more aquifer formation stability expresses less time than 28 years required to reach water level equilibrium while pumping out from the aquifer 370 % of the initial calculated recharge to the aquifer, and more aquifer formation stability expresses that the max value of drawdown is less than 2 times of the min value of Drawdown.

RECOMMENDATIONS

For any management plans to be successful in any confined aquiferthe heterogeneity index must be addressed. This is due to the fact that it has high impacts on water table drawdown, heads variations and the time for equilibrium. More studies are required for heterogeneity index to be in confined aquifer projects.

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Article History: Received: July 02, 2019, Accepted: Sep 28, 2019