Research Article

SOHAG JOURNAL OF SCIENCES

https://doi.org/10.21608/sjsci.2022.171452.1042

Effects of Groundwater Abstraction and Desalination Brine Injection on a Middle Miocene Aquifer of the El-Dabaa Area, Northern Coast of Egypt

Ashraf Embaby, Ayman Ahmed, Tawfiq Mahran, Ahmed El-Sayed*, Ahmed M. Masoud

Geology Department, Faculty of Science, Sohag University, Sohag 82524, Egypt

**E-mail: ae786765@gmail.com*

Received: 29th October 2022, **Revised:** 20th November 2022, **Accepted:** 27th November 2022.
Published online: 1st January 2023

Abstract: The lack of freshwater supplies in the El-Dabaa area on the northern coast of Egypt is a challenge to development plans, particularly concerning the groundwater aquifer limits. Saltwater desalination is a reliable solution to water shortages. This study was conducted to assess the environmental impact of the abstraction operations from the groundwater in the Middle Miocene aquifer and the effect of the rejected brine resulting from the desalination plant on groundwater using numerical modeling. The calibrated transient model was used to predict the impacts of rejected water discharge. The forecasting scenario results indicate the decline of the aquifer's potentiometric surface to reach its maximum value of 1.4 m at well 3 within the study area by 2040. The radius of the affected area by drawdown is about 550 m, and the drawdown is generally decreased far away from the location of extraction wells (feeding wells). The salinity of the aquifer in the future scenario is affected by the rejected water inflow due to the high coefficient of permeability of the aquifer in the study area. The salinity increases to reach its maximum value of 40919 ppm at each reject well site and its maximum value of 37860 ppm at feed well 2 sites within the study area by the 2040 year. In contrast, most of the study area, mainly feed well 3, wasn't affected by rejected water. The radius of the affected area by salinity is about 700 m around the reject wells site by 2040.

Keywords: Groundwater modeling, scenario, El-Dabaa, Northern Coast, Middle Miocene aquifer.

1. Introduction

Egypt is among the world's most water-scarce countries, with an average annual per capita water consumption of 750 m^3 below the 1,000 m^3 world poverty line. The United Nations Organizations (UNESCO and World Resources Institute (WRI) have classified Egypt among the 30th poorest countries regarding water. They estimate that Egypt is one country facing acute water shortages. Egypt's water resources have decreased since 1970 by up to 1713 m^3/year for each person, and it is expected to decrease from the current amount to about 630 m^3/year by 2025 [1]. In the Mediterranean coastal areas, the situation is more acute. This is due to a lack of Nile fresh water reaching there, particularly along the northwestern coast, where it is primarily dependent on groundwater. Due to internal tourism, the water shortage increases rapidly in summer. So, we see that the person shares decreases throughout this season. In the northwest coastal area, the average is about 240 m^3/year; these decreases are nearly 130 m^3/year in summer. Thus, we must improve the efficiency of our water usage, particularly for reusing drinking water production and distribution resources, protecting aquifers, and combating pollution.

Due to this, in the Mediterranean coastal areas, which depend mainly on groundwater, these aquifers' development and assessment represent a high priority to many people and their investments [2]. The Egyptian government has organized several programs to develop coastal areas to boost the national economy and address the issue of population growth [3]. The El-Dabaa area represents one of the essential locations on the Northern Coast, and the area is crowded with tourist villages and agricultural and industrial communities, Moreover, the first nuclear power plant will be constructed in the El-Dabaa area. The groundwater in the El-Dabaa area, the primary water source, has several problems; limited freshwater supply, high water demand, groundwater contamination, and seawater intrusion. One of the significant options for remedying water shortages in the El-Dabaa area of Egypt and protecting its coastal aquifer is desalination technology. Desalination is already worked in the El-Dabaa area but on a small scale. A benchmark analysis of saltwater desalination was performed for reverse osmosis systems.

2. Materials and method

The groundwater model was applied in the study area using the finite-difference groundwater flow modeling program (MODFLOW) [4], which can simulate transient flow models. The model extends 5.1 km in a north-south direction and 5.57 km in an east-west direction with discretization into 51 rows and 56 columns. The pumping rate from three wells was assumed to be 7200 m^3/d (with average pumping of 2400 m^3/day/well), and the average salinity was the initial concentration based on field data collected from the relevant fields. The discharge components include pumping and outflow of groundwater to the desalination plant of the study area. Based on the above information, the model was conceptualized.

2.1. Model Calibration

Since there are many possible values for model input data, calibration is necessary to reduce the range of variability in the input data for steady-state simulations. The calibration refers to adjusting model parameters to match observed data and verifying the model [5]. Simulated groundwater heads and TDS in the study area were calibrated against the observed hydraulic heads and TDS using the available aquifer parameters as calibration targets. They were adjusted using a trial-and-error parameter estimation method through simulations [6]. The results show good agreement between calculated and measured heads and TDS with a high correlation (99%) and an error rate of less than 1.1 cm at all calibrated points.

2.2. Study Area

The study area is a part of the El-Dabaa area lying to the east of Marsa Matruh, on the northwestern coast of Egypt. El-Dabaa area is located on the Mediterranean coastal (semi-arid) zone at approximately 150 km west of Alexandria and 133 km east of Marsa Matruh. It extends between latitudes 28° 20' 00"E and 28° 23' 30"E and from longitudes 31° 02' 15 "N to 31° 05' 00"N covering an area of about 28.3 km2 (Fig. 1).

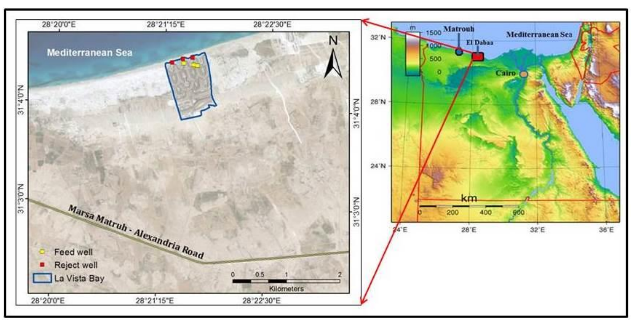

Fig. 1. Location map of the study area with selected boreholes.

2.3. Geological Setting

The stratigraphic and geological history of the area has been studied in detail, and several researchers have made significant contributions to the regional geology, sedimentology, litho-stratigraphy, and tectonic evolution of individual parts of the El-Dabaa area and the surrounding areas. The previous information on geological studies was described as follows:

The Sedimentary rocks presented in the study region belong to the late Tertiary. The Quaternary deposits are very well known and can be seen on the surface of the surrounding plateau and in the form of alluvial terraces deposited in Wadi depressions. The geological map of the study area is shown in (Fig. 2).

The regional geological investigations of the Sidi-Krier site concluded that the **significant** physiographic features in the northern and western deserts are related to tectonics [7, 8]. The fractures aligned with the Mediterranean coastal zone and display NW-SE, NNW-SSE, and ENE-WSW trends cutting the Pleistocene, Pliocene, or Miocene rock units. These fractures occur near the Mediterranean Sea shores 60 km west of the Sidi-Krier area. The topography of the Northwestern coastal zone is located between the Mediterranean Sea in the north and an escarpment of 200 m elevation in the south; moreover, this zone consists of a narrow, almost uninterrupted, band of coastal and inland dunes and interdunal plains [9].

The Miocene Marmarica homoclinic plateau, which stretches from the west of Alexandria for nearly 500 km, constitutes the northern extremity of the Northwestern Coastal Zone of Egypt [10]. This defines the coastal plain of the eastern province, which stretches from Ras El-Hekma to Alexandria, whereas the western province, which is narrow, stretches from Sallum to Ras El Hekma. The synclinal Arab Gulf embayment impacts the eastern region more significantly than the western province.

A geologic map with four stratigraphic sections is classified based on [11]:

1) Tertiary, exposed in the southern portions of the study area and constituting most of the tableland;

2) The majority of the studied region is covered by Pleistocene sediments, which include Pleistocene Oolitic limestone and alluvial deposits that formed along drainage lines in the form of Wadi terraces and Wadi fills.

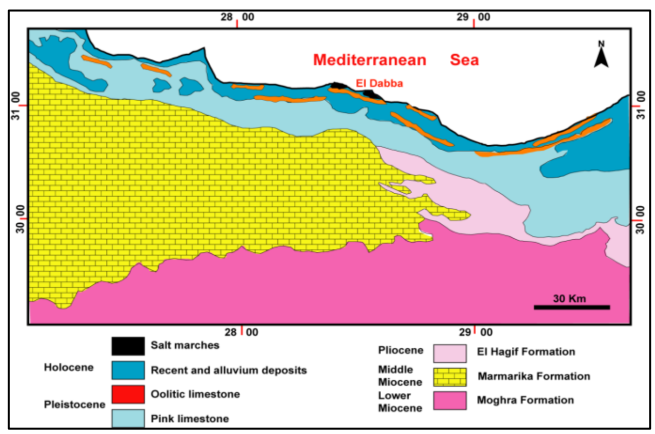

Fig. 2. Geological map of study area modified after ([12], [13]).

2.4. Hydrogeological Setting

As a part of the environmental studies, hydrogeological studies are performed to gain Knowledge of groundwater flow, its physical and chemical characteristics, and determine the direction of water flow and its velocity. This information helps develop a predicted mathematical model for groundwater level change resulting from groundwater abstraction during desalination operations.

Previous hydrogeological investigations in the study area have concluded that the El-Dabaa area includes Pleistocene and middle Miocene marine limestone aquifers. Groundwater recharge is facilitated by the structures connected to fractures and joints, which increase permeability. The high salinity levels of the coastal groundwater aquifers are due to saltwater intrusion, leaching, and dissolution processes. In addition, groundwater's salinity can rise due to human activity. The groundwater-bearing formations in the study area include the Post-Miocene aquifers consisting of an unconsolidated coastal dune (Holocene) and consolidated Oolitic limestone (Pleistocene) water-bearing units, and Miocene aquifers including a consolidated cavernous sandy limestone (Middle-Miocene) aquifer and a consolidated sandstone and sandy shale (Lower Early-Miocene) aquifer, [14].

The fractured limestone aquifer is largely fractured and composed of sequences of limestone, dolomite, and shale of the middle Miocene age (Fig. 3) [15]. Secondary porosity represents fracturing in the middle Miocene aquifer and is essential for groundwater flow. The seawater intruding into the coastal aquifer's carbonate increases their matrices' dissolution [16].

The various vulnerability degrees of contamination and salinization in the El-Dabaa area refer to seawater intrusion, and groundwater over-pumping represent the main threats to the studied aquifers [17]. They (op. cit) provide practical solutions to protect these aquifers.

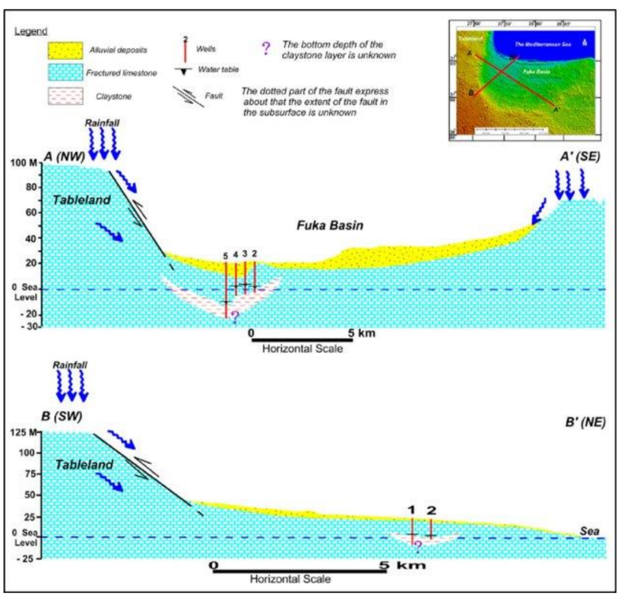

Fig. 3: Hydrogeological cross sections Fractured Middle Miocene aquifer (A–A_0 and B–B_0) in Fuka Basin modified after [18].

3. Results and discussion

The model results include the resulting hydraulic heads of the modeled area, groundwater flow, and water balance. The following is a brief description of the model results.

3.1. Hydraulic heads and groundwater flow

One of the most important results of the calibrated model is the resulting hydraulic head at any time of the stress period during the simulation of the model. (Fig. 4) shows the resulting hydraulic head map at the end of 2020.

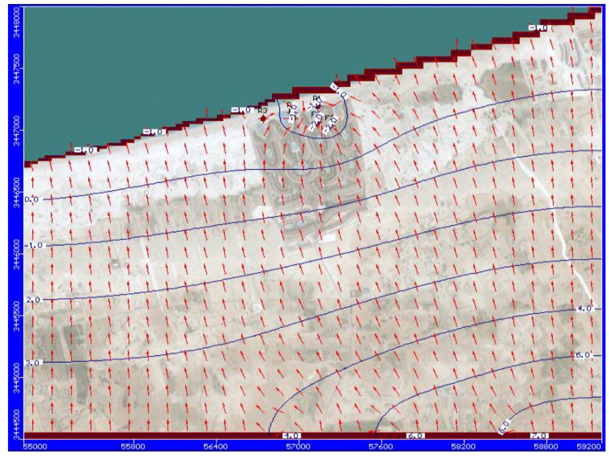

Fig. 4: Resulted hydraulic heads at the end of the simulation

3.2. Water balance

The water balance of the groundwater system comprises several components, including storage, recharge, wells, and boundary fluxes. The calibrated regional model shows the inflow and outflow components of the groundwater budget for the transient simulation at the end of the simulation (Fig. 5). The main inflow components were recharge water from rainfall and injection wells and the inflow from the seawater intrusion boundary. In contrast, the outflow components were the leakage to the Mediterranean Sea and discharged water through drilled wells. The regional water balance computed by the model is shown in (Table 1).

The calibrated model was used to apply different future scenarios to provide a forecast of the response and sustainability of the aquifer under different extraction and recharge schemes. The forecast is to expect water level declines and salinity increases in the modeled areas. Accordingly, the drawdown map, as well as the salinity distribution, can be mapped.

Table 1. Groundwater balance components values of the transient model at the end of the simulation (1460 days).

	Inflow		**Outflow**	
	Value (m^3/day)	Percent	Value (m^3/day)	percent
Constant Head	11998.15	61%	12566.55	64%
Wells	3024	15%	7200	36%
Recharge	4741.194	24%	0	0.00%
Total	19763.344	100.00%	19766.55	100.00%

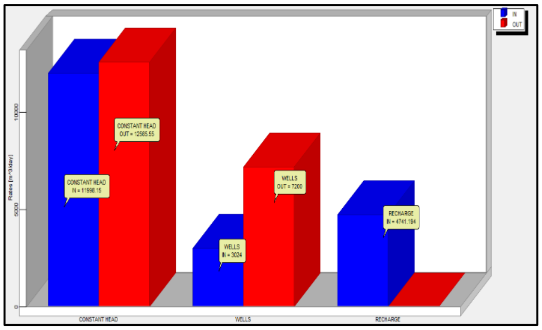

Fig. 5. Groundwater balance component of the transient model at the end of the simulation (1460 days).

Under transient conditions, the anticipated scenario was applied to study the aquifer's response for the upcoming 20 years (7300 days) to keep the present extraction and recharge rates unchanged. This includes studying the effect of pumping in the aquifer, the extent of mixing between the reject waters with the groundwater, and the circle of impact according to this scenario.

3.3.1 Drawdown of the water level

The current extraction rates of 7200 m³/d and the reject rates of 3024 m³/d for the study area are considered constant during the prediction simulation. (Figs. 6, 7, and 8) The potentiometric surface's decline will reach its maximum value of 1.4 m at well 3 within the study area by 2040. The radius of the affected area by drawdown is about 550 m, and the drawdown is generally decreased far away from the location of extraction wells (feeding wells).

3.3.2 Variations in Salinity degree (TDS)

The salinity of groundwater aquifer is increasing with more rejected water into the aquifer. The TDS value of the aquifer can be anticipated depending on the salinity value of rejected water. TDS of the aquifer in the studied area was predicted for the upcoming 20 years, as shown in (Figs. 9 and 10). It was observed that the salinity of the aquifer in the future scenario is affected by the rejected water inflow due to the high coefficient of permeability of the aquifer in the study area.

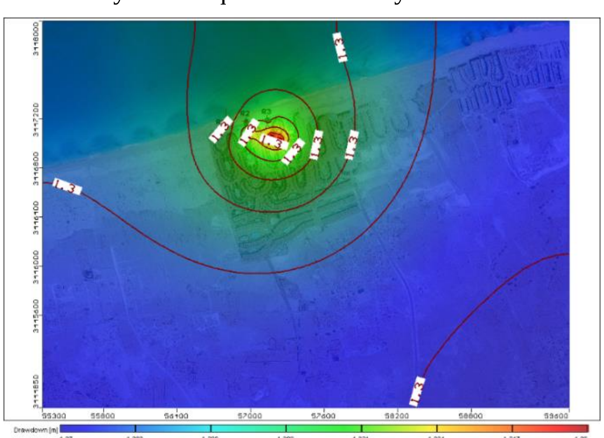

Fig. 6. Anticipated drawdown in the study area after 20 years.

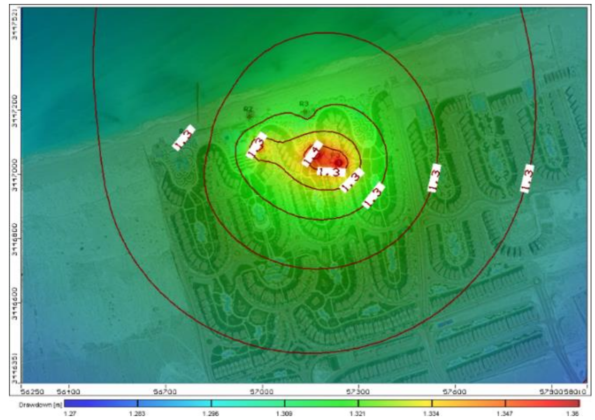

Fig. 7. Anticipated drawdown surrounding the wells after 20 years.

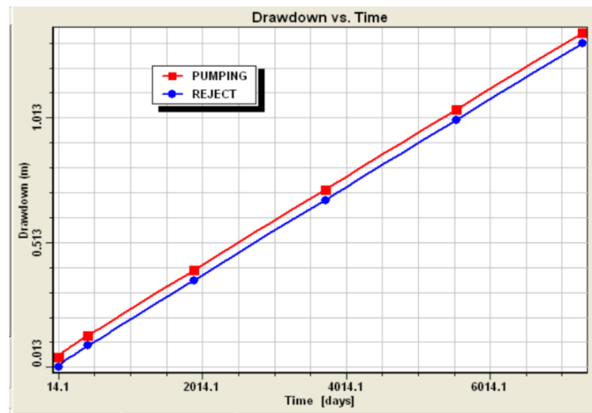

Fig. 8. Time series drawdown graph showing the continuous drawdown with time in the location of pumping and reject wells.

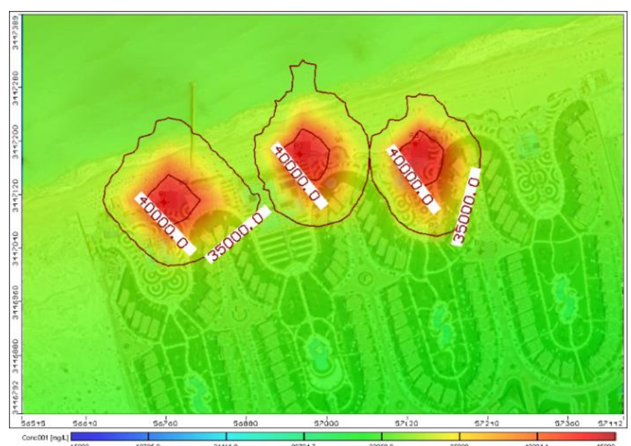

Fig. 9. Anticipated TDS concentration in the study area after 20 years.

The salinity increases to reach its maximum value of 40919 ppm at each reject well site and 37860 ppm at the feed well site (2) within the study area by the 2040 year. The radius of the affected area by salinity is about 700 m around the reject wells site by 2040. In contrast, most of the study area, mainly feed well 1, wasn't affected by rejected water.

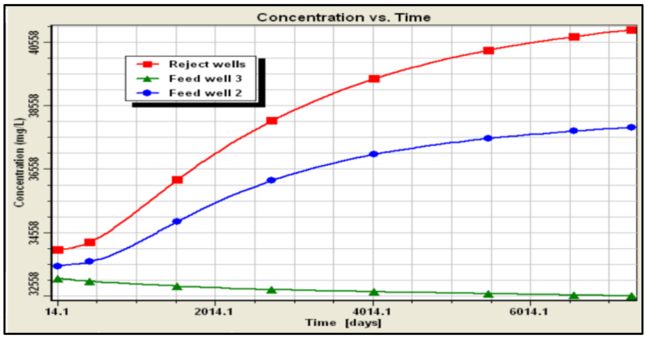

Fig. 10. Time series TDS concentration graph showing the continuous increase in TDS surrounding reject wells.

3.3.3. Discussion

The calibrated groundwater flow model of the El-Dabaa area provides a detailed description of the configuration of the hydrogeological system, the spatial distribution of the groundwater level, and the salinity value in the Middle Miocene aquifer associated with the proposed scenario of actual extraction rates.

Monitoring the groundwater levels in wells throughout the study area indicated direct hydraulic interaction between the Middle Miocene aquifer and the Mediterranean Sea. The transient model run showed an insignificant change in the groundwater level of the Middle Miocene aquifer throughout the study area, with a steady pumping rate of 7200 m^3/day by the year 2040. The potentiometric surface's decline reached its maximum value of 1.4 m by 2040; this low drawdown is due to the decrease in the hydraulic conductivity of the aquifer, the low rates of discharge represented by only four wells and compensating for the water lost through the return water from desalination processes, which is injected into the aquifer through reject wells **[19]**.

Moreover, the salinity increased to reach its maximum value of 40919 ppm surrounding the reject wells because brine water from the desalination process was injected into them. The low hydraulic conductivity significantly contributed to the concentration, and non-proliferation of salinity surrounding reject wells **[20]**.

4. Conclusion

This study aims to assess the status of the impacts of the water treatment operations on groundwater at the El-Dabaa region using a three-dimensional groundwater flow model. The continuous groundwater abstraction from the Miocene aquifer led to a groundwater drawdown and increasing salinity. A groundwater flow model was developed to simulate the groundwater management options for the different stresses within the aquifer and to predict the environmental impact of the present and future groundwater extraction schemes on the exploitation sites.

The calibrated model was used for further prediction simulations to investigate the aquifer's response to the different management options in the next 20 years. The extraction scenario was suggested to investigate the most feasible groundwater management option regarding the groundwater demand and the economic depth of groundwater.

The simulation of the actual extraction rates of scenario the extraction scenario indicated that by 2040 the average drawdown in the study area would be about 1.4 m, and the average concentration of salinity in the study area will be about 37860 ppm at feed well 2 site and 40919 ppm at each reject the well site. It is concluded that by 2040 the current extraction and salinity rates might be under the permissible, affordable rates for the groundwater management of the aquifer.

Based on the groundwater availability and demand, the proposed economic lifting depth, and the development ambitions for the aquifer, the application of the actual extraction rates of the extraction scenario was found to be the best management option that meets these topics.

References

[1] H.M. Moghazy, M.M. Sobeih, G.A. Kamel, E.E. Helal, M. A. El Hadad, Engineering 49 (2010) 147-157.

[2] N. El Arabi, International Journal of Environment and Sustainability (IJES), 1 (2012) 3.

[3] A.I. Embaby, M. Razack, M. Le Coz, G. Porel, , Journal of Water Resource and Protection 8 (2016) 293-310.

[4] M.G. McDonald, A.W. Harbaugh, Technical report, US Geological Survey (1988).

[5] V.P. Singh, D.K. Frevert, Water Resources Publication: Littleton, CO, USA (2002).

[6] S.A. Honnanagoudar, Ph.D. Thesis, National Institute of Technology Karnataka, Surathkal India 16 (2015) 184.

[7] R. Said, The geology of Egypt. Elsevier. Amsterdam 5(4) (1962) 377.

[8] E.M. El Shazly, A.B. Salman, I.E. El Aassy, El Rakaiby, Ann Geol Surv Egypt IX (1979) 551-563.

[9] A.T.A. Moustafa, N.M. EL-Mowelhi, N. In Van Duivenbooden, M. Pala, C. Studer and C.L. Bielders (eds.). Efficient soil water use: the key to sustainable crop production in the dry areas of West Asia, and North and Sub-Saharan Africa, (1999)

[10] H.M. El-Asmar, P. Wood, Quaternary Science Reviews 19 (2000) 1137-1149.

[11] M. Yousif, O. Bubenzer, Springer Environ Earth Sci 69(7) (2013) 2227–2246.

[12] Rizk, Z.S., Davis, A. D., Ground water 29(2) (1991) 232-238.

[13] El-Bayomi, G. M., Forum Geographic 7 (2009) 14-22.

[14] Guindy, K. H., Ph.D thesis, Fac. Sci., Ain Shams Univ., Cairo, (1989) 151.

[15] G.A. Omar, Master's Thesis, Menoufia University, Al Minufya, Egypt, (2008).

[16] G.T. Chae, S.T. Yun, S.M. Yun, K.H. Kim, Ch.S. SO, Hydrological Sciences Journal 57(8) (2012) 1672–1683.

[17] U.A. Abu Risha, N. Sturchio, Research Journal of EnvSci 6(3) (2018) 174-186.

[18] M. Yousif, O. Bubenzer, Appl Water Sci. 2 (2012) 15–28.

[19] I. Abd-Elaty, A. E.L. Shahawy, S. Santoro, E. Curcio, and S. Straface. Science of The Total Environment 795 (2021) 148928.

[20] M. Abualtayef, H. Al-Najjar, Y. Mogheir, A. K and Seif, Arabian Journal of Geosciences 9 (2016) 10.